N170 Visual Word Specialization on Implicit and Explicit Reading Tasks in Spanish Speaking Adult Neoliterates

Laura V. Sánchez

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ABSTRACT

N170 VISUAL WORD SPECIALIZATION ON IMPLICIT AND EXPLICIT READING TASKS IN SPANISH-SPEAKING ADULT NEOLITERATES

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Adult literacy training is known to be difficult in terms of teaching and maintenance (Abadzi, 2003), perhaps because adults who recently learned to read in their first language have not acquired reading automaticity. This study examines fast word recognition process in neoliterate adults, to evaluate whether they show evidence of perceptual (automatic) distinctions between linguistic (words) and visual (symbol) stimuli. Such a mechanism is thought to be the basis for effortless reading associated with Visual Word Form Area activation that becomes “tuned” to scripts as literacy skills are acquired (McCandliss, Cohen, & Dehaene, 2003). High density EEG was recorded from a group of adults who are neoliterate in two reading tasks: (1) a one-back task requiring implicit reading (available only to those who have attained automaticity), and (2) reading verification task, an explicit reading task, in which participants detected mismatches between pairs of visual and auditory words. Results were compared to recordings from a comparison group of adults who learned to read in childhood. Left-lateralized N170 ERP was targeted as an index of automaticity in reading. Participants from the comparison group showed left-lateralized N170 to word stimuli in both the implicit and explicit reading tasks. Conversely, N170 effects were not found on the participants form the study group on either implicit or explicit reading tasks. This suggests that automaticity in reading can be indexed in neoliterate

adults using the ERP component N170, and that automaticity had not been acquired by the study group investigated here.

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DEDICATION

To the Catequistas Dolores Sopeña

for your support to disadvantaged communities. For reminding us that no matter where we are, or what we do, there is always an opportunity to create a better world for those in need.

A las Catequistas Dolores Sopeña

por su esfuerzo constante en el trabajo con comunidades en desventaja. Por recordarnos que no importa dónde estamos o qué hacemos, siempre existe la oportunidad de crear un mundo mejor para aquellos en necesidad.

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L.V.S

Chapter I

INTRODUCTION

Literacy is defined as “the ability to use printed and written information to function in society, to achieve one’s goals, and to develop one’s knowledge and potential” (Murray, Kirsch, & Jenkins, 1997, p.17). Advances in technology and the complexity of communication today place a great emphasis on literacy, making it a crucial skill for everyday life. Reading ability has acquired such a level of importance that it has been considered a human right under the Hamburg Declaration (CONFITEA, 1997). However, in the world, 15.9% of the adults older than 15 years of age lack the ability to read and write (World Bank, 2010). Illiteracy rates are higher in developing countries, where up to 40.3% of the adult population is considered illiterate (World Bank, 2010). Even in developed countries, there are a significant number of people who cannot read (or read well enough to fully participate in society). For example, approximately thirty million people have below basic literacy skills in the United States, according to the 2003 National Adult Literacy Survey, NAAL (Kutner, Greenberg, Jin, Boyle, Hsu, & Dunleavy, 2007). This means that their reading skills do not go beyond being able to use a set of simple and concrete literacy abilities, such as locating easily identifiable information in short common text or following simple written instructions.

Below basic levels of literacy, in an increasingly complex world, can bring people to a vulnerable socioeconomic position that is likely to be transferred to the following generations (Fletcher, 2010).

Martínez and Fernández (2010) classify the implications of low literacy levels into five categories: health, education, economics, social integration, and cohesion. Regarding health, it has been shown that it is more likely for people with below basic literacy skills to lack understanding of basic concepts of health, self-care, and hygiene, making them more susceptible to illness. And even when they understand the concepts, following instructions on medication is often challenging (UNESCO, 2006). In terms of education, people with low literacy levels tend to have lower educational aspirations for themselves and their family members (Carneiro, Meghir & Parey, 2007). The economic aspect has to do with the limited possibilities for finding jobs that generate better incomes to bring the family above the poverty line (Riveros, 2005; Goicovic, 2002). This is because usually the jobs that offer economic and educational opportunities require more than below basic literacy levels. Regarding social interaction and cohesion, important social contacts require the understanding and use of written media. Since people who have below basic literacy cannot fully understand written content, the access to relevant information is limited. And this, in fact, limits their participation in society (UNESCO, 2006).

1.1 Statement of the problem

Research has shown many benefits to be associated with improving literacy levels in the adult population. People who attend adult basic education programs usually obtain better paid employment positions, are more likely to have better physical and mental health, have less probability to have children who struggle in school, are more likely to participate actively in society, and tend to have less discriminatory attitudes toward others (Bynner, McIntosh, & Vignoles, 2001). Notwithstanding these benefits, challenges remain for both adult literacy students and program developers, as there is evidence that the effects of adult literacy training are only moderate (Sabatini, Shore, Holtzman, & Scarborough, 2011) and that relapses into illiteracy are common (Abadzi, 2003a; Niwaz, Zaman, Dahar, Faize, & Tahirkheli, 2010).

In order to assess specific challenges to adult basic education, it is necessary to define the population and sub-populations of low-literate adults very carefully, since this is an extremely heterogeneous group. According to Miller, McCardel, and Hernandez (2010), the low-literate population includes people (1) who have not learned or have not been adequately taught to read and write; (2) whose first language is not the language in which they are acquiring literacy for the first time; (3) with learning disabilities; and (4) who just want to improve their reading skills. In terms of actual reading skills, a cluster analysis conducted by Mellard, Fall, and Mark (2009) on the skills of low-literate adults showed three different profiles: (1) those who were unable to rapidly apply the print to sound reading rules they already know; (2) those whose attentional resources are over-compromised when trying to read, therefore considered non-automatic readers; and (3) those who have relatively adequate reading skills but struggle with comprehension.

The present study targeted the challenges associated with learning to read in adulthood after having no access to formal education in childhood. Since the people who form the focus of this research are adults who have just finished their literacy training, I have adopted Abadzi's (2003b) terminology "neoliterate" to refer to this sub-population.

Neo (from the Greek *neos*) means “new”; therefore, they will be referred to as “new readers” to differentiate them from the broader low-literate group.

To understand the low achievement scores and indicators associated with adult literacy programs, there is a need for research that targets not only the instructional philosophy and strategies that serve as the design impetus for many of these programs, but also the cognitive mechanisms underlying the learning processes common to adult learners. Abadzi (1996, 2003a) reported that one of the most salient characteristics of adults who recently learned to read is a lack of automaticity. Their reading is very slow, and not accurate enough to be able to understand what they read. These readers tend to fail in the fast application of the reading rules they already know (Mellard et al., 2008). The development of reading automaticity usually requires a great deal of practice, much more than typically provided in adult literacy classes or than adult learners can dedicate to the task personally (Sabatini et al., 2011).

Automaticity is achieved when a task is performed using the fewest possible attentional resources (LaBerge & Samuels, 1974; Samuels, 2004). The component steps that comprise reading and comprehension constitute demands on limited attentional and processing resources. In order to dedicate resources to reading comprehension, other important processes, such as language comprehension, decoding, fast word recognition, and application of searched, inferred, or computed information (White & McCloskey, forthcoming), must be performed smoothly, fast, and unconsciously – therefore, automatically. Thus, if reading automaticity is not mastered, reading comprehension is likely to be compromised. As in a vicious cycle, sporadic use of reading skills decreases the likelihood of attaining automaticity, thereby increasing the risk of relapse into illiteracy.

Known evidence of writing systems dates back about 5,400 years. According to Dehaene et al. (2010), reading is a relatively recent skill, which means that humans might not have developed yet a genetic mechanism that could be available for transfer down through successive generations. The hypothesis that the brain needs to rewire itself to execute emerging demands is referred to as "neuronal recycling" by Dehaene et al. Taking reading as an example, in the absence of a uniquely dedicated area or set of neurons to support a reading function, the brain uses areas typically dedicated to other cognitive functions to create reading pathways. Specifically, from the visual system, it uses areas related to object recognition; and from the language system, it uses areas related to phonological processes (Schlaggar & McCandliss, 2007). Changes in the visual system obtained by intensive training in reading, specifically in the left occipito-temporal region or the left fusiform area, are thought to be responsible for the smooth, effortless, fast, and therefore automatic reading abilities shown by expert readers (Cohen et al., 2000; Dehaene et al., 2010). Expertise in reading creates a visual specialization for common written patterns, and this specialization could be part of the "automaticity" construct that was proposed by LaBerge and Samuels (1979) and Samuels (2004) as a crucial precursor for reading comprehension.

It is postulated that observed differences in brain activation from people who are literate and illiterate are (at least in part) attributable to the fact that literate individuals are typically taught to read in childhood, while people who are illiterate do not have such exposure. A series of studies (by Castro-Caldas, Petersson, Reis, Stone-Elander, and

Ingvar (1998); Castro-Caldas et al. (1999); Castro-Caldas and Reis (2000, 2003); and Castro-Caldas (2004)) found that illiterate participants showed less activation in brain areas related to phonological processes, specifically the left inferior parietal gyrus; and more activation in general-purpose, episodic memory-related areas, specifically the middle frontal/frontopolar region, compared to literate participants. These results strengthen the idea that learning to read in childhood has a profound impact on brain organization later in life.

However, reading-related brain reorganization has also been demonstrated in adults who are illiterate but who are in the process of acquiring literacy. In fact, studies by Carreiras-Seghier, Baquero, Estévez, Lozano, Devlin, and Price (2009) and Silva-Nunez, Castro-Caldas, DelRio, Maestú, and Ortiz (2009) show that when reading is acquired in adulthood, there is an enhancement of brain activity in areas related to phonological processing and higher level visual processing. However, when adults learn to read, even though reorganization of brain activations may be observed, the activation patterns differ from those observed in the brains of adults who learned to read in childhood (Dehaene et al., 2010; Silva-Nunez et al., 2009). For example, neoliterate adults show more bilateral activation, compared to the left lateralized activation seen in expert readers, during language and literacy-related tasks.

Most of the studies examining brain activation and reorganization related to adult literacy and literacy acquisition have employed methods like Positron Emission Tomography (PET) and Functional Magnetic Resonance Imaging (fMRI). These methods provide precise spatial resolution; in other words, they allow investigators to know what regions in the brain are involved in a specific cognitive process, such as word recognition. However, because these technologies measure metabolic indices of brain activation, they are limited with respect to temporal resolution – that is, the timing (in milliseconds) of brain activations associated with cognitive processing, and the sequencing of different cognitive events (but see Friston, Zarahn, Josephs, Henson, & Dale, 1999; Burock, Buckner, Woldor, Rosen, & Dale, 1998, who used stochastic and rapid event-related designs with fMRI, allowing faster identification of the signal). Temporal resolution at the millisecond level is important in the current study, since the variable of interest comes from the ability to recognize words, a very fast process. Eye-tracking studies of reading have shown that a person fixates on a word in text for approximately 200-250 milliseconds (e.g., Sereno & Rayner, 2003). This means that all the visual and linguistic information required to recognize a word needs to be gathered in this short period of time. One of the methods that could allow targeting this extremely rapid process is Electroencephalography (EEG). EEG is a non-invasive technique for recording electrical activity generated by the brain. It detects voltage variations through electrodes that are placed on the surface of the scalp. The variations are expressed as positive and negative deflections relative to voltages recorded from a reference electrode. By segmenting and averaging the recorded voltages, time-locked to the specific stimulus or event, it is possible to derive event-related potentials (ERPs) from the EEG recordings (Rugg & Coles, 1995). ERPs provide an index of the brain's electrophysiological responses that are associated with processing of an internal or external stimulus. ERPs are captured with millisecond precision and are thus particularly suited to examining processes that unfold very rapidly in time (Dien, 2010). Many ERP components are labeled by their polarity (i.e., the direction of the voltage fluctuation) and latency in milliseconds. This means that their names begin with either P (positive) or N (negative), indicating the direction of the associated voltage deflection, followed by a number that indicates the timing or sequencing of that particular positive or negative deflection. For example, the ERP component to be explored in this study is referred to as the “N170”, reflecting the fact that it is most often observed as a negative voltage deflection that occurs around 170 milliseconds post stimulus presentation. Each ERP component is thought to reflect a combination of perceptual or cognitive processes related to the specific stimulus that has been presented to the participant. For example, N100 is related to the perception of sound (Näätänen & Picton, 1987), N170 is related to visual expertise (Bentin, McCarthy, Perez, Puce, & Allison, 1996), P300 is related to attentional resource allocation and categorization (Polich, 2007), N400 is related to semantic processing (Kutas & Federmeier, 2000), and P600 is related to syntactic processing (Friederici, 2002). Other ERP components are labeled by their specific function, such as the Error-related negativity (ERN), a negative deflection that occurs following an erroneous response to a task (Wessel, 2012). ERPs are particularly useful in this current study, since reading behaviors reflect the coordination of multiple and rapid sensory, cognitive and linguistic process. In order to isolate aspects from that rapid behavior –such as word reading automaticity- it is crucial to use methods of high temporal resolution.

Imaging methods with high temporal resolution have been used to explore brain activity in adults who are illiterate and neoliterate, but so far have been limited to auditory word memory tasks (Ostrosky-Solís, Arellano García, & Pérez, 2004), and visual word memory tasks (Castro-Caldas et al., 2009). These investigaitons have revealed that early activation of auditory word recognition tends to be more left lateralized for participants who are literate and more bilateral for participants who are illiterate (Ostrosky-Solís et al., 2004). This distribution difference is thought to reflect the recruitment of language-specialized regions of the left hemisphere that support rapid, automatic processing of language-related stimuli. For illiterate people, less specialized regions across the brain are involved. Latency difference between literate and neoliterate brain responses during word recognition have also been reported, with literate participants demonstrating faster auditory recognition of words than illiterate participants (Castro-Caldas et al., 2009). It is important to note that these results were obtained from tasks that did not target pure reading activities. They involved spoken language and memory tasks, in addition to reading. There is a gap in the literature regarding the time course of fast word recognition as seen in adults who learned to read in adulthood, while controlling for whether or not they achieved reading expertise (automaticity).

The term "visual word specialization" has been used to refer to expertise at the perceptual level in word recognition (Maurer & McCandliss, 2007). This aspect of specialization to support reading processes in the brain has been studied by examining the N170 ERP component, described above as a negative voltage deflection that occurs at around 170 milliseconds post-stimulus presentation. The distribution of ERP components over different parts of the brain provides valuable information about the neural systems that are involved in generating these responses. In the case of the N170, left lateralization (that is, primary involvement of the left hemisphere of the brain) has been associated with a fast (therefore automatic) visual processing for words (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Maurer, Brandeis, & McCandliss, 2005; Maurer, Brem, Bucher, & Brandeis, 2005; Maurer et al., 2006; Maurer & McCandliss, 2007; Maurer, Blau, Yoncheva, & McCandliss, 2010).

This study used EEG to explore the N170 ERP as an index of word recognition automaticity in people who are neoliterate, while the participants performed specific reading tasks that manipulate the required level of reading expertise. The characteristics of the N170 ERP (its field strength, peak amplitude, distribution, and timing) provided indications of the presence or absence of reading automaticity. The tasks developed for this study specifically target the left fusiform area, a brain region that has been shown to be associated with effortless, smooth, and automatic reading (Cohen et al., 2000). The use of high density EEG, 128 channels, allowed the capture of millisecond-by-millisecond brain responses thought to be associated with these reading tasks. In addition, although indirect, some topographical information reflecting differences in reading tasks was obtained and helped to determine whether amplitude difference between conditions came from identical topographies (stronger in one condition compared to other) or from different topographies (that may or may not have the same global strength) (Maurer & McCandliss, 2007).

By comparing the brain responses of adults who are neoliterate with those who learned to read during childhood, we hope to shed some light on basic cognitive processes involved in learning to read as an adult – especially the phenomenon of automaticity. This information has the potential to provide valuable insights that could guide future research and potentially enable the development of best practices guidelines for adult literacy instruction, including the amount and type of practice needed during instruction and familiarization for an adult to attain reading automaticity.

This investigation was focused on native Spanish speakers learning to read in Spanish. There are two main reasons for choosing this population. In the first place, Spanish has a transparent orthography, which means that the correspondences between sound and symbols are highly consistent (Ellis et al., 2004). It has been shown that the clearer the grapheme-phoneme correspondence, the more evident the N170 component is (Maurer & McCandliss, 2007). Also, choosing a transparent orthography is essential to rule out the use of other processes that could influence reading, such as sight word and irregular word reading, and other strategies thought to facilitate reading in non-transparent orthographic systems (e.g., reading by analogy). The second reason is because of the challenges faced by the growing Hispanic population in the United States as they seek full participation in society. Sixty percent of Spanish-speaking low-literate adults scored on the below basic literacy level, and many of these were non-literate in their native language (i.e., Spanish), or in the language of residence (i.e., English) (Greenberg, Macías, Rhodes, & Chan, 2001). Not only are they experiencing the challenges faced by low-literate native English-speakers, but also when they try to learn to speak and read in English, they have the additional hurdle of trying to do so in their second language (Dufva & Voeten, 1999). For this population, access to literacy programs in one or both languages (i.e., Spanish and/or English) is critically important to their becoming self-supporting and contributing members of their adopted communities. Conversely, a lack of viable literacy programs would logically be a major contributing factor in limiting academic and employment opportunities for this target population.

This dissertation is structured as follows. In the next chapter, I provide a literature review of the theories of reading commonly used in adult literacy settings. The discussion is focused on single word recognition, an important process in reading, and its neurophysiological indicator (Activation from the Visual Word Form Area, and N170 ERP component). In Chapter III, I present the hypotheses from the current study. Chapter IV contains the design and methods. Chapter V explains the Data pre-processing and data analysis. Chapter VI displays the results. And finally in Chapter VII I present the conclusions, discussion, limitations, and recommendations for further studies.

Chapter II

REVIEW OF THE LITERATURE

2.1 Theoretical Framework

Various theoretical frameworks for reading have been proposed. These place great emphasis in a sub-component of reading thought to be one of the main predictors of reading comprehension, word recognition. In this chapter, I first provide an overview of the theory of reading most used in the adult literacy. Following, I present a review of two theories regarding word recognition. And finally, the neurophysiology of word recognition is discussed as it relates to the experiments developed for the current study about reading automaticity in adults who are neoliterate.

2.1.1 Simple View Theory of Reading: Why Study Word Recognition in Adult Literacy?

The so-called Simple View Theory of reading holds that reading comprehension is a simple process derived from two different processes: language comprehension and decoding (Gough & Tunmer, 1986). In this framework, *language comprehension* refers to the use of word level (lexical) information to achieve discourse interpretation; and *decoding* (under this theory) is defined as the ability to isolate words quickly, accurately, and silently; in other words, fast word recognition (Hoover & Gough, 1990). The model considers language comprehension and decoding as equally important processes for reading. This means that one of them would not suffice to achieve reading comprehension, but the interaction between the two processes is what allows this achievement to take place. The model can be represented by the following formula:

Reading comprehension (RC) = Language comprehension (LC) x Decoding (D)

The authors suggest that a multiplicative model is more appropriate than an additive model for two reasons: necessity and non-sufficiency—necessity, since the two components (language comprehension and decoding) need one another to be able to contribute to reading comprehension; and non-sufficiency, because one, in the absence of the other, does not predict reading comprehension (Hoover & Gough, 1990). Empirical investigations based within this theoretical framework were conducted by Hoover and Gough, who tracked 254 Spanish-English bilingual students from kindergarten to fourth grade. The analysis was based on data from 210 first graders, 206 second graders, 86 third graders, and 55 fourth graders. Participants were tested using subtests from the Interactive Reading Assessment System, administered annually. Three subtests were evaluated: pseudoword reading (as an index of decoding skills); language comprehension (listening to, and answering questions on, a short passage); and reading comprehension. Two regression models that represented the additive model (R = a +b1D + b2L), and the interactive model (R = a + b2D + b2L + b3[D x L]) were compared. They found that the multiplicative model accounted for significant variance over and above the additive model. Conversely, other authors have suggested that both the additive and the multiplicative models provide good reading comprehension predictions (Dreyer & Katz, 1992; Joshi & Aaron, 2000) and concluded that the main advantage of the Simple View of reading is its emphasis on the importance of both decoding and language comprehension for reading comprehension.

Sabatini et al. (2010) evaluated the validity of this theory in a study with a population of adults who had low literacy levels. Based on the idea that the Simple View could be too simple to capture what is going on in reading, they compared three different models: (1) the Simple View (as an additive model); (2) the Simple View with the addition of vocabulary as a third variable; and (3) the Simple View plus vocabulary and fluency as additional variables. Participants in this study consisted of 476 adults with low literacy levels, 66% female, from 16-76 years of age (mean = 36.9, SD = 13.7), who reported to have received around 9 years of formal education.

Through the use of confirmatory factor analysis, a test of assumptions about the relationship between variables by the use of unobserved variables called factors, the researchers found that the Simple View approach provided a better fit to the data than the two more complex models, implying that language comprehension and decoding are the two variables that account for most of the variance in reading comprehension. The other variables (vocabulary and fluency) did not add explanatory power to the extended models.

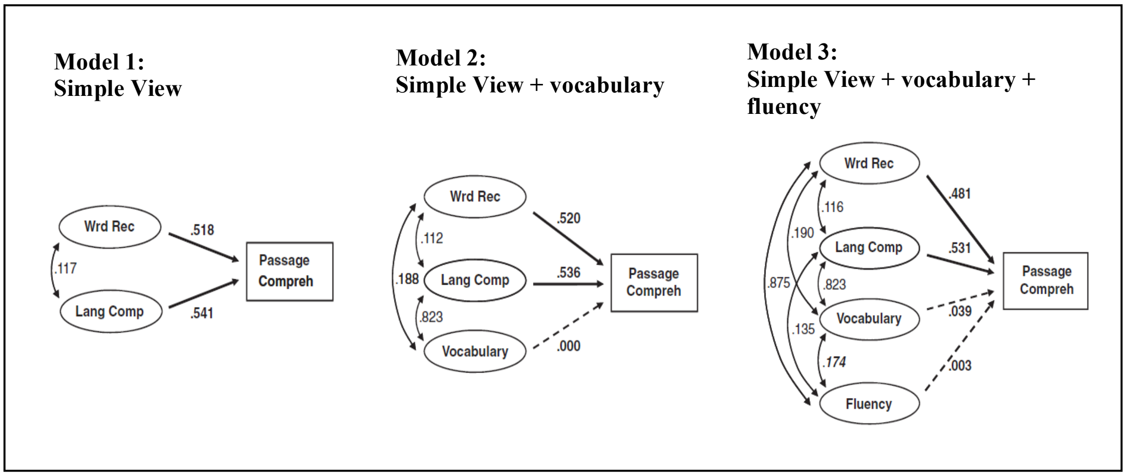


Figure 1: Reading comprehension models for adult literacy students

Model proposed by Sabatini et al. (2010)

One disadvantage of the Simple View Theory is that it construes the concepts of decoding, language comprehension, and reading comprehension very broadly, and there is no reference within this theoretical framework to more narrowly defined concepts thought to be associated with word recognition. For example, the decoding concept is not concerned with the use of any specific strategy, such as grapheme-phoneme conversion or analogy, known to support fast and accurate word recognition (Hoover & Gough, 1990). In order to address this limitation, Mellard, Fall, and Woods (2010) re-defined and identified sub-components of the two main variables of the Simple View Model: decoding and language comprehension. This expanded model divided decoding into two skills: phonemic decoding (knowledge of the combination of letters and sounds) and word reading (either from the use of grapheme-phoneme conversion or whole-word reading). On the other hand, since language comprehension is considered a complex process, the authors included variables such as auditory working memory and vocabulary knowledge that are expected to contribute to both listening comprehension and reading comprehension. In addition, they included speed of processing and fluency as exogenous variables in the model, since the former has been shown to be important in fluent reading (Sabatini, 2002), and the latter is thought to reflect effective integration of many skills that are needed to read texts (such as inference, vocabulary access, and contextual connection) (Wolf & Katzir-Cohen, 2001). Three hundred nine adults with low literacy levels, 60% female, mean age 32 years (SD=15.2) were tested on a skill that was determined to provide an index of each variable from the model.

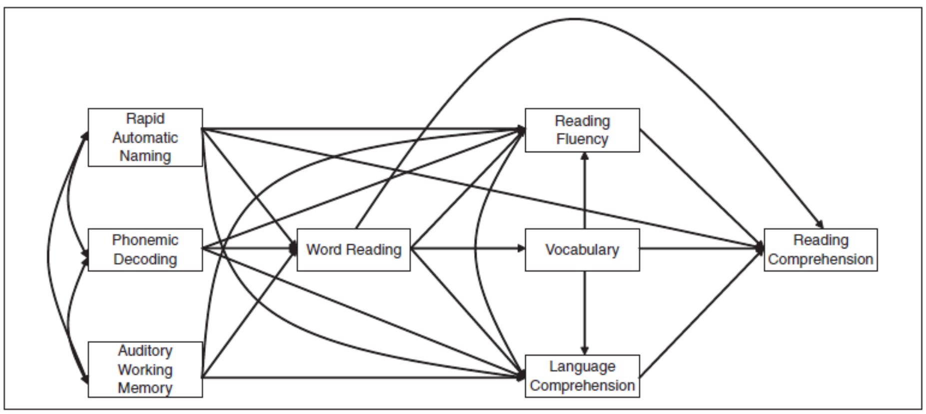


Figure 2: Hypothesized Reading Model for adult literacy students

Model based on an expanded version of the Simple View (Mellard et al., 2010).

A path analysis, a modeling approach that identifies the specific correlations between the components of a model, was conducted on the scores of the variables. Significant correlations were found between the following subcomponents of the model: phonemic decoding and word reading; word reading and reading fluency; word reading and vocabulary and reading comprehension; vocabulary and language / reading comprehension; reading fluency and reading comprehension; auditory working memory and language comprehension; speed of processing and fluency; and language comprehension with reading comprehension (See figure 3).

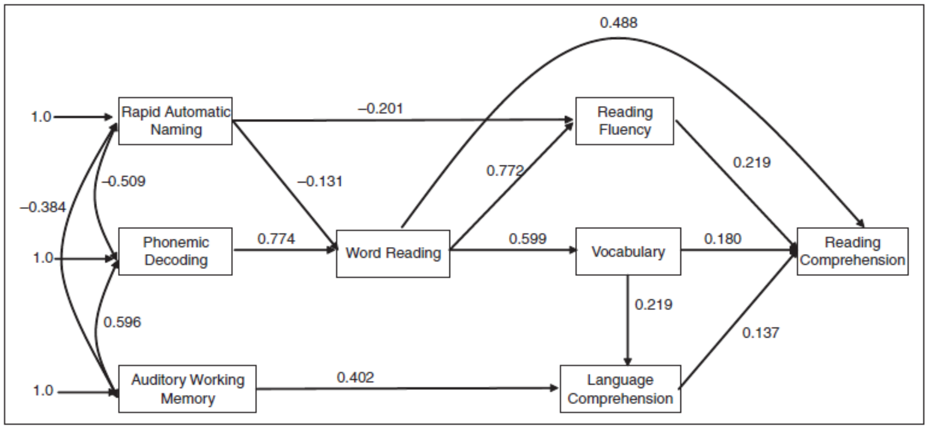


Figure 3: Path Analysis Results for the Expanded Simple View Model

By Mellard et al., 2010.

This expanded model contributed to obtaining a more precise description of how struggling adult readers perform reading tasks, and how the sub-components of the simple view theory of reading interact in this population. In terms of word recognition, since adult readers performed better in word reading than in phonemic decoding, the authors concluded that due to deficiencies in phonemic decoding, adult readers tend to rely more on whole word orthographic processes in reading tasks. On the other hand, the correlation between language comprehension and reading comprehension was weaker than expected. The authors suggested that for struggling adult readers, reading comprehension could be more influenced by the ability to recognize words than the ability to understand language. This supports the view that word recognition skills are crucial for the achievement of reading competency, and consequently there is a need to study word recognition in adults who are acquiring literacy.

Given the demonstrated importance of the ability to recognize words in both a general population of readers as well as adult literacy students, here I provide a discussion of our current understanding of the cognitive and neuroanatomical aspects of word recognition.

2.1.2 Models of Visual Word Recognition

Two of the most influential theoretical approaches to explaining visual word recognition will be described in these sections: The Dual-Route approach (Coltheart, Curtis, Atkins, & Haller 1993; Coltheart, Rastle, Perry, & Ziegler, 2001), and the Parallel Distributed Processing approach (Harm & Seidenberg, 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). Although both models provide theoretical accounts for word recognition, they differ in their assumptions regarding the representation of words in the systems. The dual-route approach is based on the Modularity Hypothesis (Coltheart, 1999; Fodor, 1983), which delineates the view that the mind is composed of different specialized structures (mental modules) that operate fast, automatically, and in a domain-specific manner. This means they have evolved to process specific kinds of input. In other words, complex cognitive processes (such as reading) consist of other definable and identifiable sub-processes. Dual-route models describe word recognition as a series of modular interactions between distinct subsystems; under this view, there are at least two possible ways to read a word (lexical and non-lexical) (see review in the following section). On the other hand, the Parallel Distributed Processing approach is based on a Connectionist framework. Connectionism was developed to provide computational models that simulate aspects of human perception, cognition, learning, and behavior, as well as storage and retrieval of information from memory (McClelland & Cleeremans, 2009). In general, Connectionism views cognitive processes as cooperative and competitive interactions of units formed in a network of nodes. Typically, units in network models are constrained by activations and inhibitions from both bottom-up and top-down processes meant to simulate sensory and/or executive-level initiated processes, respectively. Cognitive representations, under Connectionist views, are derived from repeated interactions between such units as emergent properties of these interactive systems.

In the sections below, I provide a more detailed outline of each of these two theoretical approaches to reading.

2.1.2.1 Dual-route word recognition model. According to the dual-route model, there are two possible ways to read words: (a) a route that follows print to sound rules, and (b) a route that functions like a mental dictionary "lookup" process (Coltheart, 2005; Coltheart et al., 1993; Coltheart, Patterson, & Marshall, 1980). The first one, the grapho-phonological or indirect route, uses fixed grapheme to phoneme conversion rules to decode words. A grapheme is a visual representation of a particular sound in a given language (Henderson, 1985). It could be a letter, two letters, or more, such as *th* or *igh* in English (Coltheart, 1978). In a language with regular orthography, when a novel word is presented, given that the system has not been exposed to it yet, the word is decomposed into its minimal pieces (graphemes), and each grapheme is paired with the corresponding phoneme. With constant exposure, the word is learned, and stored in the mental lexicon, which acts like a mental dictionary. The second route, the lexicosemantic or direct route, consists of the association between the word form and the meaning, and does not depend on having to phonologically process its parts. This route is used to read familiar words and has special importance in processing irregular words, which are impossible to decode by using grapheme-phoneme conversion rules. The preference and weight of one route or the other can be determined by the transparency of the language (Das, Padakannaya, Pugh, & Singh, 2011). Ijalba-Peláez and Cairo-Valcárcel (2002) suggest that in languages with transparent orthographies, such as Spanish, the grapho-phonological route tends to be the default mechanism to approach reading new words, while the lexicosemantic route is used when the word has been learned over time, reflecting expertise.

The probable existence of these two routes has been supported by evidence from studies of patients who have suffered brain injuries. These studies assess different reading performances in patients that had suffered from left temporo-parietal or occipito-temporal lesions. Some patients tend to make more semantic-contextual errors but are able to perform grapheme-phoneme conversions, while others present difficulties with grapheme-phoneme conversion but are able to read familiar words and to recognize words as a whole (e.g., Dérouesné & Beauvois, 1979; Funnell, 1983; Marshal & Newcombe, 1973). This double dissociation led researchers to conclude that there must be at least two ways in which words can be recognized. Cases of phonological dyslexia (difficulties reading via the grapho-phonological but not lexicosemantic route) and deep dyslexia (difficulties reading using the lexicosemantic, but not grapho-phonological route) have also been reported in Spanish, which suggests that the existence of two routes for reading also applies to languages with transparent orthographies (Ferreres & Jacubovich, 2003).

Jobard, Crivello and Tzourio-Mazoyer (2003) performed a meta-analysis of fMRI and PET studies on word recognition tasks in typical readers and concluded that different neuronal networks were activated for grapho-phonological and lexicosemantic processes during word recognition. The meta-analysis included studies that either contained stimuli targeting one of these routes or tasks that heavily relied on one of the routes. Studies elicited the grapho-phonological route by the use of pseudowords, Japanese kana (syllabic alphabet), or by using phonological decision tasks. The lexicosemantic route was elicited by the presentation of irregular words, Japanese kanji (ideographic characters), or lexical and semantic decision tasks.

The meta-analysis showed that tasks related to the grapho-phonological route activate the left posterior superior temporal gyrus (Horwitz, Rumsey, & Donohue, 1998; Price, Wise, & Frackowiak, 1996; Sakurai et al., 2000) and the left superior temporal gyrus (Hagoort et al., 1999; Price, Moore, & Frackowiak, 1996; Rumsey et al., 1997; Sakurai et al., 2000)**,** areas that have been associated with phonological processing (Wise et al., 1991). Activation was also found in the left middle temporal gyrus (Booth et al., 2002; Herbster, Mintun, & Nebes, 1997; Paulesu, Frith, & Frackowiak, 2000; Rumsey et al., 1997; Sakurai et al., 2000), an area related to semantic processing. An area associated with phonological decision, the supramarginal gyrus, was also active when eliciting the grapho-phonological route (Booth et al., 2002; Mummery, Patterson, Hodges, & Price, 1998; Price, Moore, & Frackowiak, 1996a). Additional activations were seen in the opercular part of the left inferior frontal gyrus (Booth et al., 2002; Fiebach, Friederici, Müller, & Von Cramon, 2002; Hagoort et al., 1999; Xu et al., 2001) and the triangular part of the left inferior frontal gyrus (Fiebach et al., 2002; Horwitz et al., 1998; Paulesu et al., 2000; Rumsey et al., 1997). These areas are related to the subvocal rehearsal system (Paulesu, Frith, & Frackowiak, 1993), working memory (Fiez et al., 1996), and the manipulation of phonology (Fiez, Balota, Raichle, & Petersen, 1999). This particular route requires the use of working memory resources, since the results of early decoding must be held online for integration with subsequent decoding of groups of letters.

For the lexicosemantic route, the meta-analysis found that information gets transferred from the left occipito-temporal junction (Cappa, Perani, Schnur, Tettamanti, & Fazio, 1998; Horwitz et al., 1998; Sakurai et al., 2000) and lingual gyrus (Fiebach et al., 2002; Hagoort et al., 1999; Rumsey et al., 1997) to areas related to semantic processing, such as the middle temporal gyrus. Activation of the occipito-temporal region is related to visual word expertise (Cohen et al., 2000), and activation of the lingual gyrus relates to the processing of orthographically legal strings (Petersen, Fox, Snyder, & Raichle, 1990). It is important to note that these areas are also active during grapho-phonological processing, indicating that the grapho-phonological route is a complex system requiring phonological analysis, whereas the lexico-semantic route is more direct and less reliant on additional processing.

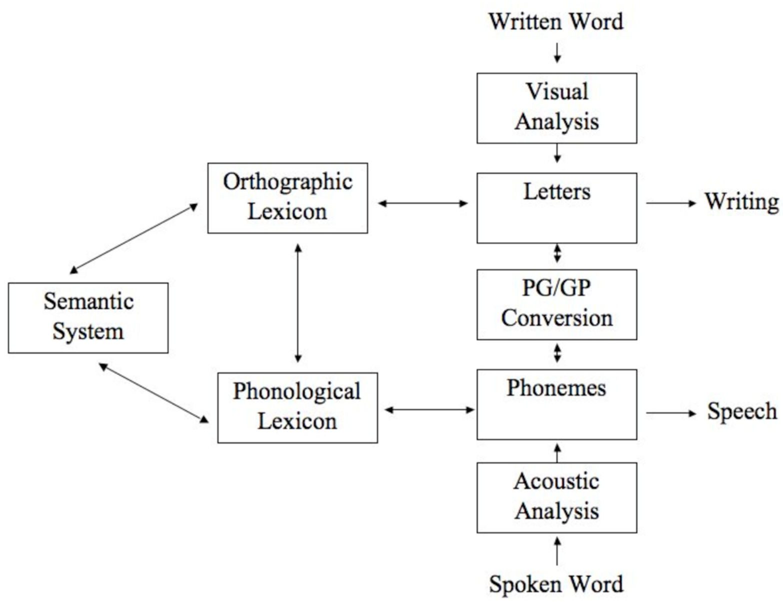


Figure 4: Dual-route Model Diagram

by Rapcsak, Henry, Teague, Caranaha, and Beeson (2007).

2.1.2.2 Parallel Distributed Processing Models of Word Recognition. Originally proposed by Seidenberg and McCelland (1989), the Parallel Distributed Processing (PDP) models consider word recognition as a bidirectional and parallel interaction between three levels of representation: orthographic, phonological, and semantic. In contrast to Dual-Route models, PDP models consider any lexical process to be the set of distributed codes that represent the attributes of the words. Word recognition is the process of activating and inhibiting the appropriate set of codes within the levels of representation. Instead of having a subdivided system where one sub-component is responsible for one type of word and a different sub-component takes care of other types (such as the Dual-Route models, where unknown words and pseudowords are usually processed by the non-lexical route, and the known words and irregular words by the lexical route), in PDP models the whole system is active regardless of the type of written stimuli that have been presented (either real words or pseudowords, regular or irregular words, familiar or unfamiliar words). The connections between the three levels need to be learned through repeated exposures and error-corrections. This means that every time the model is exposed to a word, it adjusts the weights between the levels, based on input and output. Over repeated exposure, the system stabilizes and forms an appropriate, accurate activation pattern for each specific stimulus. The process of exposure and learning in such a model is often computationally modeled, and this approach has been used to shed light on questions about reading acquisition (McClelland & Cleeremans, 2009).

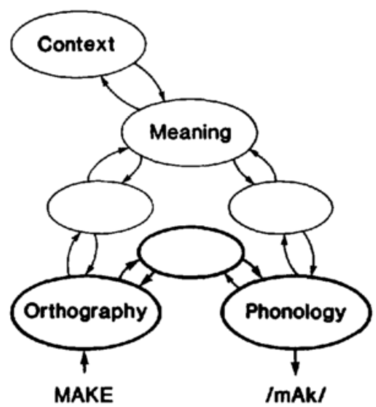


Figure 5: Parallel Distributed Processing Model Diagram (Seidenberg & McClelland, 1989)

2.1.2.3 Dual-route vs. PDP Models. There are three main differences between the Dual-route models and PDP models (Coltheart, 2006): The first one has to do with either having a local vs. a distributed system. Dual-route model proponents believe that there is a local representation of words in the mental lexicon, while PDP model proponents argue that word representation is within the whole network; therefore, there is no specific location for a mental lexicon.

The second difference has to do with parallel vs. serial processes. The grapheme-phoneme conversion in a Dual-route model is in fact a serial process where the activation occurs as a sequence of steps. On the other hand, PDP models, as their name indicates, consider the word recognition process to be an activation of the whole network simultaneously.

The third main difference is that PDP models, since most of them are computational models, attempt to simulate learning of word recognition. The computational model starts with an input, a set of pathways between the levels of representation, and output, which is then compared to the expected/correct response. This process is repeated as many times as needed, with many different words, until the system adjusts the relationships between the levels of representation to finally yield a stable network. When this happens, the system has "learned" the word. On the other hand, Dual-route models are intended to instantiate a steady-state, adult-like system, and there is no attempt within this theoretical framework to simulate learning.

Both theoretical frameworks, despite their differences, contribute to our overall understanding of the processes involved in word recognition. From the Dual-route perspective, it has been shown by anatomical brain research that there are specific structures that are more or less in charge of some specific rule-governed sub-processes of word recognition (Jobard et al., 2003). What is still unknown is how the brain specializes these specific structures to support word recognition, and how the rules get established. From a PDP perspective, it is clear that word recognition is a highly interactive process involving many subsystems working together and that exposure during learning is a crucial factor (McClelland & Cleeremans, 2007).

Most of the evidence about word recognition in adults who are literate, illiterate, and neoliterate comes from comparison between separate orthographic and phonological processes (e.g., Greenberg, Ehri, & Perin, 1997, 2002; Ijalba-Pérez & Cairo-Varcárcel, 2002), a perspective that is more compatible with a broadly Dual-route approach to reading. However, the current study is not an attempt to evaluate the relative strengths of the two major theoretical perspectives per se, since it attempts to tap into a more sensory brain mechanism: a visually-oriented analysis that determines whether a visual stimulus is language-based or not. This mechanism happens at the perceptual level, but it is highly influenced by both orthographic and phonological awareness in a top-down manner (Maurer & McCandliss, 2007). This process of visual identification for language-like features in a written stimulus could indicate "automaticity" in the word recognition process (see the discussion of the Visual Word Form Area in the sections below).

2.1.3 Word Recognition in Adult Neoliterates: Behavioral Evidence

The relationship between word reading abilities and phonological abilities was tested in Spanish-speaking adults who learned to read in adulthood (Villa Carpio Fernéndez, Defior Citoler, & Justicia Justicia, 2002). To test for word reading abilities, researchers used word, non-word (combination of letters in a way that is not permitted in the participant's language), and pseudoword (combination of letters in a way that is permitted in the participant's language) reading tasks; and to test for phonological abilities, they used phoneme segmentation, deletion, substitution, merging, and rhyming tasks. Fourteen low-income Spanish-speaking women who learned to read in adulthood (mean age 56 ± 20) participated in this study. Participants showed better performance in word reading than in pseudoword and non-word reading. Since pseudoword and non-word reading depends on phonological processes, these results indicate possible difficulties with the grapho-phonological route. With respect to phonological abilities, participants performed poorly in tasks involving rhyme detection and sound deletion. A positive correlation was found between phonological awareness and pseudoword and non-word reading, but no correlation between phonological awareness and real word reading was observed. Recruitment of the grapho-phonological route for pseudoword and non-word reading could indicate the use of such skill during reading acquisition as a mechanism for self-learning (the ability to use the grapheme-phoneme conversion rules in new words) and reading improvement. Given the low scores on pseudoword, non-word, and low frequency word reading, it was concluded that adult literacy students could have a non-efficient phonological route that makes them rely more on the lexico-semantic route.

A preference for the lexico-semantic route rather than the grapho-phonological route was also observed in English-speaking adults with low literacy skills (adults with reading levels below 7th grade), evidenced by better performance in tasks that depend on orthographic processes (such as choosing which pseudoword looks more similar to real words, letter position detection, spelling and rhyme detection) than phonological processes (that is, non-word reading, deletion, segmentation of sounds in words) (Greenberg et al., 1997). In addition, low literate adults tend to use orthographical strategies even in tasks that depend on phonological processes (Greenberg et al., 2002).

When addressing fast and automatic word recognition, timing becomes a crucial variable (Wolf, 1999). One of the behavioral measurements that have been used to target fast word recognition is “rapid automatic naming” (RAN) (Wolf, Bowers, & Biddle, 2000). In RAN tasks, participants are asked to say the names of a series of visually presented pictures, colors, letters, or digits as fast as they can, while accuracy and response time are recorded. It has been proposed that RAN is a predictor of word recognition and retrieval (Wolf & Bowers, 1999), separate from phonological awareness (Swanson, Trainin, Necoechea, & Hammill, 2003), a process that has been considered one of the most important reading predictors (Ziegler & Goswami, 2005). However, the relationship between RAN and reading is still not clear (Arnell, Joanisse, Klein, Busseri, & Tannock, 2009).

In adult literacy settings, it is common to see slower RAN rates in adult literacy students compared to literate participants (Sabatini, 2002). Sabatini explains that in adult literacy students, slow processing speed (evidenced by slow naming rates) can overload working memory, thereby limiting the ability to transfer information to long-term memory. This is thought to have a negative impact on both skill acquisition via procedural memory and on the transfer of content to semantic memory. Thus, in reading, slowness with grapheme-phoneme conversion can lead to the cycle of not being able to decode fast enough to become competent in this critical skill, which in turn undermines the ability to execute fast word recognition. This cycle leads to a failure to achieve reading automaticity. The challenge when measuring RAN and its relationship with reading is that RAN is a multi-componential skill, since it has been shown to be related to speed of processing, phonological awareness and phonological prediction, efficient stimulus encoding into working memory, rapid identification of stimulus, motor planning/vocal production, and eye movement, among others (Arnell et al., 2009). An fMRI study (Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003) showed that RAN activates brain areas related to reading, including the inferior frontal cortex, temporo-parietal areas, and the ventral visual system. Orthographic processing is associated with the ventral visual system, while phonological processes are associated with temporo-parietal areas. This suggests that RAN is a complex task that involves many processes, not only limited to reading abilities (Arnell et al., 2009); nevertheless, it correlates with aspects of literacy development in adults (Sabatini, 2002).

Based on the knowledge that adults who are acquiring literacy could face difficulties with phonological processing and speed of processing, which are important for reading acquisition, Royer, Abadzi, and Kinda (2004) conducted a study to analyze changes in reading performance after training in one, two, or none of these processes. Four hundred twenty-five participants were assigned to one of four training groups: a group that would receive phonological awareness training; another group that would receive rapid identification of words training; another that received both; and a control group that would receive the standard reading instruction. Participants who had training in one or both skills showed better reading performance than participants who received the standard reading training.

In summary, adult literacy students seem to struggle with a crucial sub-component of reading, namely, grapheme-phoneme conversion, possibly compounded by inefficient use of decoding. They might use orthographical strategies as a compensation for the phonological difficulties, but this strategy is not efficient either, probably due to the lack of reading automaticity. Training in phonological awareness and processing speed has been shown to help with reading ability in adults who recently learned to read, but the actual process of reading automaticity in adults who are neoliterate is still unknown. While behavioral measures may offer a broad indication of the use and importance of some learning strategies over others (e.g., specific decoding strategies) in developing reading competency, these measures might not reflect sub-processes that unfold very rapidly in time. Neuroscientific methods, such as EEG, have the ability to index neural events associated with cognitive processes on the millisecond level, so that processes can be examined in fine-grained detail, taking into account the basic sub-components that might not be evidenced using behavioral measurements (Dien, 2010). Moreover, neurophysiological measures do not depend on behavioral responses, thus minimizing participant bias.

In the following sections, some relevant contributions of neuroscience to adult literacy research will be described.

2.2 Contributions from Neuroscience to the Adult Literacy Research

Research on the neural bases of reading in people who did not learn to read during childhood started well before non-invasive brain imaging techniques were available. Initial evidence comes from the observation of clinical manifestations of patients who suffered strokes. For example, Lecours and Parente (1989) explored the role of literacy in left-brain specialization for language using behavioral measurements. They conducted a battery of tests on adults who had suffered from left or right peri-Sylvian stroke and who were either literate or illiterate, and the findings were compared to those from healthy adults who were either literate or illiterate. The consequence of a left peri-Sylvian stroke is usually aphasia, a language disorder that interferes with the ability to understand or produce language. In this particular study, both the literate and illiterate participants who had left hemisphere damage presented aphasic symptoms, indicating left-hemisphere dominance for language regardless of reading skill. However, participants from the illiterate group that suffered from right hemisphere stroke achieved lower naming scores than participants from the literate group, who had suffered the same type of stroke. Naming is a task usually involved with left-hemisphere activation. The fact that naming scores were impacted by right hemisphere damage in illiterate participants indicates that in this group, the right hemisphere could have an important role in language processing. Even though there is a left-hemisphere dominance for language in participants who are illiterate, they were engaging several neural systems in order to perform language processing, whereas the people who were literate developed more focused activations and narrowly defined pathways (Lecours & Parente, 1989). This finding is important for the present study, since reading is a language-related task; therefore, the way language is represented in the brain will mediate the way reading gets automatized.

Current neuroscientific research explores brain activations related to cognitive processes by looking at spatial and/or temporal dynamics of neural responses to specific stimuli. Methods with higher spatial resolution, such as Position Emission Tomography (PET) and Functional Magnetic Resonance Imaging (fMRI), allow the identification of active anatomical brain regions during such tasks. PET detects glucose metabolization in the brain, while fMRI detects blood oxygenation levels. The consumption of both glucose and oxygen by the brain is assumed to index brain activity in specific regions that are actively involved in specific tasks (Allen, Scott, & Gregory, 2006). Higher temporal resolution methods, such as Electroencephalography (EEG) and Magneto-encephalography (MEG), capture indices of very rapid neural processing on the order of milliseconds (msecs) and therefore are able to better index the time course over which processes unfold in the brain. EEG detects voltage variations that are related to inter-neuronal signaling, and MEG detects magnetic field fluctuations associated with the traveling electrical field potentials that are generated by inter-neuronal communication (Handy, 2005; Luck, 2005).

Neuroscientific research focusing on adult literacy has followed two major lines of investigation, one related to studies on illiterate participants, and the other related to neoliterate participants. Studies that compare literate versus illiterate participants provide valuable information about the profound effects that literacy acquired during childhood has on brain organization. Most of these studies target language processes, since skills like visual word recognition have not been acquired in the illiterate population. On the other hand, studies comparing literate and neoliterate participants provide information on how brain areas related to reading acquisition are modified when the ability is acquired later in life.

2.2.1 Studies Contrasting Participants who are Literate and Illiterate

Castro-Caldas, Petersson, Reis, Stone-Elander, and Ingvar (1998) conducted a PET study to explore the effects of literacy in spoken language. A group of 6 monolingual Portuguese illiterate women (mean age 65, SD = 5) and a group of 6 monolingual Portuguese literate women (mean age 6, SD = 6) were included in this study. Participants were asked to repeat blocks of high frequency words and pseudowords while being scanned. Pseudowords were constructed by modifying the consonants of real words, while holding the word structure constant. Behavioral results showed that the literate group performed more accurately in both word and pseudoword repetition than the illiterate group. Pseudoword repetition error analysis showed that it was common for illiterate individuals to transform pseudowords into real words and that they had more phonological errors than semantic or lexical errors. This finding is similar to what other behavioral studies have found (e.g., Greenberg et al., 1997, 2002; Villa Carpio Fernández et al., 2002). Brain data results showed that both groups recruited the same brain regions in word repetition (left middle and inferior temporal gyri, left inferior parietal region, and left dorsolateral prefrontal cortex). These areas are associated with lexicosemantic processing and memory (Stoeckel, Gough, Watkins, & Devlin, 2009). Conversely, brain activity discrepancies between groups were found during pseudoword repetition. Participants who were literate (but not those who were illiterate) showed increased activation in the left anterior cingulate, associated with the attention systems (Pardo, Pardo, Janer, & Raichle, 1990; Raichle et al., 1994); right frontal operculum/anterior insula, related to declarative memory retrieval and automaticity in language processes (Petersson, Elfgren, & Ingvar, 1997); left lentiform nucleus from the basal ganglia, important for speech and language processes (Aglioti & Fabbro, 1993; Poline, Vandenberghe, Holmes, Friston, & Frackowiak, 1996; Warren, Smith, Denson, & Waddy, 2000); and anterior thalamus, seen to have a role in word retrieval (Rosen, Ojemann, Ollinger, & Petersen, 2000). Participants from the illiterate group, on the other hand, presented increased activation in the right middle frontopolar region, which acts as a general-purpose support system, related to episodic memory (Rugg, Fletcher, Frith, Frackowiak, & Dolan, 1996; Tulving, 1995). Caramazza (1997) proposed that there are two types of phonological processes: one related to spoken language, and another one related to written language. According to the author, the differences between the groups in pseudoword repetition are related to fact that there is no lexicosemantic representation of pseudowords, so participants depend on phonological strategies to be able to perform this task. Literate participants have developed written phonological processes that activate the areas mentioned before, as opposed to illiterate participants, who need to use general-purpose structures to perform the task. The authors proposed that when people learn to read, there is a change in the level of phonological processing, from an unconscious to conscious, as a consequence of learning an alphabetic orthography. It seems that illiterate individuals may not bring phonological awareness to a conscious level, evidenced by failing to activate the left inferior parietal gyrus. Behaviorally, this difference is represented by difficulties with pseudoword repetition in the illiterate group.

In a follow up study, Castro-Caldas and Reis (2000) found that, in addition to showing left vs. right activation differences (generally stronger left activation for literate than illiterate participants), the groups presented inter-hemispheric differences, especially in the posterior parietal cortex. The majority of the left hemisphere activation from the literate group in the posterior parietal cortex was coming from inferior parts of the angular/supramarginal gyrus, whereas in the illiterate group, the left hemisphere activation was coming from the superior parts of the angular/supramarginal gyrus. The original results of the study (Castro-Caldas et al., 1998) were re-evaluated using a network analysis approach**.** In this analysis, researchers created a model of interacting structures organized in five sub-networks with their respective regions of interest (ROI): auditory input, phonological loop, articulatory motor output, attention, and central executive. Within-group results showed that the network interactions were different for reading words in comparison to pseudowords in the illiterate group, but were the same in the literate group. Between-group results showed similar network interactions in both groups when reading words, but not when reading pseudowords. The authors concluded that learning to read changes brain organization by allowing access to phonological information from visual inputs, thereby adding a visuo-graphic representation to oral language. These results must be interpreted with caution, since in this methodological design, the authors did not contrast these conditions with a language-neutral condition that would eliminate activations that could be present in either linguistic or non-linguistic tasks.

Using Magnetic Resonance Imaging (MRI), Castro-Caldas et al. (1999) investigated possible anatomical changes in the corpus callosum after learning to read. They hypothesized that the brain regions related to reading in individuals who had not learned to read would not have been constantly activated; therefore, these regions should be less developed compared to the same regions in individuals who had learned to read. A group of 18 right-handed illiterate women (mean age 62.6 ± 5.6) and a group of 23 right-handed literate women (59.9 ± 6.1) were part of this study. Researchers found less callosal density in the illiterate group compared to the literate group, markedly so in the intraparietal cortices. Therefore, the communication within the parietal cortex is augmented in literate participants. The parietal cortex is related to phonological processing as well as spatial abilities.

Using ERP techniques, Ostrosky-Solís, Arellano-García, and Pérez (2004) conducted a study contrasting the performance of literate and illiterate participants in an auditory probe task. Fourteen participants comprised the literate group (mean age 41.2 ± 6.2), and seven people with no reading experience were part of the illiterate group (mean age 40.8 ± 6.4). The auditory probe task consisted of the presentation of a probe sound while engaging in a language task. Participants had to attend to the probe stimulus during a control condition and ignore the probes while memorizing a list of words in the experimental condition. ERPs were derived from EEG recorded during the probe stimuli in both the control and experimental tasks. For this paradigm, attenuation of left hemisphere activity in response to probe stimuli is expected when participants are involved in the word memorization task. This hypothesis rests on the key idea of resource allocation, which proposes that word memorization (a language related activity) requires activation of language areas (typically left hemisphere), and therefore suggests that there would be less left hemisphere resources remaining for processing the unattended probe stimuli. Behavioral results showed that the literate and illiterate groups performed equivalently on the probe task. For their ERP analysis, researchers targeted the N1 and P2 components. In order to obtain task-specific attenuation to the probe stimuli, the authors used the ratio of the amplitude of the ERPs from the experimental condition, divided by the ERPs from the control. Values equal to 1 would indicate no change in activation from one condition to the other, while values smaller than 1 would indicate different probe response attenuation between the control and experimental condition. Two types of analysis were conducted: inter-hemispheric and intra-hemispheric. For the inter-hemispheric analysis, a group (literate vs. illiterate) by hemisphere (left vs. right) analysis of variance was conducted. Results showed that both literate and illiterate participants presented left hemisphere response attenuation to the unattended probe stimuli during word memorization, indicating that this linguistic process (of memorizing the list of words) was using left hemisphere resources, leaving less left hemisphere resources available for the probe stimuli. For the intra-hemispheric analysis, a group (literate vs. illiterate) by region (frontal, fronto-temporal, temporo-central, and parieto-temporal) analysis of variance was conducted on each hemisphere separately. The authors found significant differences between the groups in the parieto-temporal region, in which the illiterate group showed less attenuation to the probe stimuli than the literate group. This indicates that illiterate participants might not engage this region as much as literate participants in verbal memory tasks. The fact that both groups showed left hemisphere attenuation to the unattended probe stimuli means that the targeted language processes are taking place in the left hemisphere, so lateralization of language remains the same within groups, which is consistent with previous research (Lecours & Parente, 1989). The differences in recruitment of parieto-temporal regions might indicate that participants who are illiterate have less involvement of phonological processing than participants who are literate, which is consistent with the work of Castro-Caldas et al. (1998).

In summary, research on literate and illiterate adults has shown that learning to read in childhood has an effect on the way the brain performs cognitive processes related to language. Specifically, researchers have observed a stronger left lateralization for language, more callosal density in parietal regions, and increased intra-hemispheric connectivity in adults who learned to read as children, compared to their illiterate peers (Castro-Caldas et al., 1998, 1999; Castro-Caldas & Reis, 2000). Areas related to phonological processing, such as the parietal area, do not develop the same way in people who are exposed to reading and those who are not. One explanation could be the fact that reading is a recent cultural construct, and there are no designated areas in the brain to perform this behavior (Dehaene et al., 2010). In order to read, the brain fine-tunes regions related to other processes in oral language and visual domains (Schlaggar & McCandliss, 2007). Since adults who are not literate have not had exposure to reading instruction and thus have not had exposure to the experiences thought to trigger this fine-tuning, differences in brain organization between these two groups are to be expected.

2.2.2 Anatomical and Functional Differences Between Literate and Neoliterate Participants

A study on the anatomical brain differences between literate adult participants and neoliterate adult participants by Carreiras-Seghier et al. (2009) revealed clear structural differences between the groups. The study compared MRI data from 20 monolingual Spanish-speaking neoliterates and 22 monolingual Spanish-speaking illiterates. They found that the neoliterate group showed more gray matter than the illiterate group in the bilateral dorsal occipital areas, which are related to higher level visual processes; left supramarginal and superior temporal areas, associated with phonological processing; and both the angular gyrus and posterior middle temporal, regions thought to be involved with semantic processes. In addition, the neoliterate participants were found to have more white matter in the splenium of the corpus callosum. Having more white matter in the corpus callosum indicates an enhancement of interhemispheric communication; and more grey matter in language and visual regions indicates an early specialization that recruits neurons that process reading within the language-dominant hemisphere. This suggests that even when acquired later in life, literacy has the potential to change brain organization. It might not necessarily be the same neural changes that people who learned in childhood experienced, but something that needs to be explored to determine if it would be possible to make it more functional, and more automatic.

Silva-Nuñez, Castro-Caldas, Del Rio, Maestú, and Ortiz (2009) introduced the topic of adult literacy instruction to the discussion of “sensitive periods” for reading skill acquisition. The concept of a sensitive period proposes that cognitive skills are more easily acquired during specific developmental periods (Knudsen, 2004). Late literacy acquisition might imply that, since the skill is not acquired during an "expected" time period, the reorganization of the brain might be different in late learners as compared to people who learned to read in childhood. Silva-Nuñez et al. (2009) suggested that before comparing any literacy group, the methodological design must account for typical brain changes that occur in the aging brain. The HAROL model (hemispheric asymmetry reduction in older adults) proposed by Cabeza (2002) suggests that adult people tend to recruit areas from both hemispheres in tasks that younger people would perform unilaterally. With the HAROL model and the concept of sensitive period in mind, Silva-Nuñez et al. (2009) contrasted brain activity from a group of 12 literate Portuguese-speaking women (73 ± 9.6) and 7 neoliterate Portuguese-speaking women (70.86 ± 7.4) using MEG, in an auditory recognition task. Participants were asked to listen to a list of words and then identify whether or not they had heard them, discriminating them from a list of distractors. The behavioral performance (reaction times and error rates) was no different between the two groups. However, brain data showed differences between them. Control participants engaged more left than right hemisphere resources during the discrimination task, whereas neoliterate participants showed no significant asymmetries between left and right hemispheric activations, indicating a more bilateral process. In addition to left hemisphere activation, control participants showed right inferior frontal activation in late sources (active after 400 msecs post stimulus onset), supporting the hypothesis of bilateral activation in the aging brain proposed by the HAROL model. However, neoliterate participants showed right hemisphere activation in both early and late sources (before and after 400 msecs), indicating that the HAROL model by itself is not sufficient to explain more right activation in auditory recognition tasks in neoliterate individuals. The authors confirmed their hypothesis of a difference in information processing in those who learned to read later in life, compared to those who learned in childhood.

An MEG study was conducted to investigate brain activity during a visual memory task in 7 neoliterate women (mean age 70.86 ± 7.4) and 5 literate women (mean age 73 ± 9.6) (Castro-Caldas et al., 2009). Participants were exposed to a list of 33 words before being scanned and were asked to identify those words from a list of unlearned words during scanning. Both neoliterate and literate participants showed the same amount of cortical source activation. However, the sources were different between the groups. Greater hemispheric asymmetry was found in literate participants, with stronger activation in the left hemisphere, especially the inferior frontal gyrus. Conversely, neoliterate participants showed less asymmetrical distribution of activation in the hemispheres and stronger activation in the right hemisphere, especially the middle temporal gyrus. Time window analysis indicated no significant differences in activation in the early time window (around 100 msecs post-stimulus), but a significant difference in the late time window (around 400 msecs post-stimulus). Although not significant, there were more late areas of activation in the neoliterate group than the literate group. The authors concluded that literacy, when acquired later in life, recruits different brain networks from those recruited when the skill is acquired in childhood. Neoliterate adults seem to process words in a slower and more holistic way that involves right hemisphere activation in addition to involvement of language regions, while the brains of literate adults seem to more rapidly process information about orthographic representations in the left hemisphere, reflecting the suggestion that literate individuals have quicker access to visual decoding than those who are neoliterate (Castro-Caldas et al., 2009).

In summary, it seems that the brains of literate people have adapted both anatomically and functionally, through training, to perform reading tasks. However, the brains of illiterate people do not show evidence of similar reorganization. Specifically, illiterate individuals show no evidence of conscious phonological processing when carrying out language tasks, specifically in tasks that require phonological processing, such as pseudoword reading (Castro-Caldas et al., 1998). When learning to read occurs later in life, the reorganization of the brain is different from the reorganization that occurs when literacy is acquired in childhood (Carreiras et al., 2009; Castro-Caldas et al., 2009; Silva-Nuñez et al., 2009). Importantly, there is behavioral and physiological evidence that neoliterates engage in a more effortful and time-consuming process during reading than do literates (Dehaene et al., 2010).

Neuroscientific studies using fMRI, PET, MEG, and EEG technology to examine brain activation in illiterate and neoliterate adults have provided considerable information about the neural anatomical and functional differences underlying the behavioral performance of these groups. However, these studies have offered little explanation as to why adults often do not reach full proficiency when they learn to read later in life and why they may not become fluent readers. To shed light on such questions, investigations of the specific area of the brain thought to be associated with automaticity in word recognition (i.e., the Visual Word Form Area) have been conducted.

2.1.3 The Visual Word Form Area

Warrington and Shallice (1980) describe the visual word form system as "that [mechanism] which parses (multiply and in parallel) letter strings into ordered familiar units and categorizes these units visually. The components can range in size from graphemes, syllables, morphemes to whole words" (p. 109). This categorization occurs before any phonological and lexical analysis takes place. The existence of the visual word form system implies that there also exists some abstract representation of visual stimuli, since processing a word form via the visual system does not depend on the perceptual dimensions of the stimulus, such as the location, size, and font (Price & Devlin, 2003).

Neuropsychological studies have shown that impairments in the word form system result in an acquired dyslexia called word-form dyslexia (Warringon & Shallice, 1980), or spelling dyslexia (Warrington & Langdon, 1994). Patients with this disorder tend to read single words accurately by identifying one letter at a time. Reading is effortful, and reaction times (as well as error rates) increase with increasing word length (Hanley & Kay, 1992; Warrington & Langdon, 1994). There are two possible explanations for the occurrence of this disorder. One is that the person is not able to access the visual word form system, so they use letter knowledge as a compensatory strategy to read words (Warrington & Shallice, 1980); and the other explanation is that the person does not access the visual word form system in a typical way, relying on the use of serial rather than parallel letter identification (Paterson & Kay, 1992). Both explanations agree that the reading process becomes time-consuming and extremely effortful when the visual word form system is compromised (Hanley & Kay, 1992).

In many studies, neuroscientists have concluded that processes attributed to the visual word form system are associated with activation of the left fusiform gyrus in the occipito-temporal cortex (Cohen & Dehaene, 2004; Cohen et al., 2000, 2002; Dehaene et al., 2002, 2010; McCandliss, Cohen, & Dehaene, 2003; Schlaggar & McCandliss, 2007; Vinckier et al., 2007). This area has been given the name of Visual Word Form Area (VWFA) (Cohen et al., 2010). According to Schlaggar and McCandliss (2007), the function of the VWFA during reading is to support a form of perceptual expertise for visual word recognition that enables rapid perception of visual words in one's own language.

The visual system becomes specialized for visual word recognition by re-purposing areas from the occipito-temporal cortex that are initially dedicated to general object recognition. Repeated exposure to orthographic patterns and training in grapheme phoneme conversion, in combination with maturation of these areas of the brain, likely explains how this system fine-tunes based on areas most responsive to features of the stimuli, to produce the cognitive mechanisms more efficient for the task (Schlaggar & McCandliss, 2007).

Since reading involves the transformation of representations from a visual stimulus (print) to a linguistic form, and language processes usually happen in the left hemisphere, a visual area that functions as a relay station between visual processing and language gets specialized in the left hemisphere (Schlaggar & McCandliss, 2007). When this specialization occurs, reading is likely to become efficient and automatic.

The characteristics of the VWFA are described further by McCandliss et al. (2003). They assert that this area is modality specific, since it is sensitive to written words but not spoken words. Its activation does not depend on the level of awareness, indicating that this area could process information automatically. It is more active for well-learned stimuli rather than novel ones, indicating expertise. It becomes activated regardless of the visual field of presentation (left or right), indicating an early interhemispheric transmission of information from the right to the left hemisphere for visual stimuli presented in the left visual field. It is insensitive to surface visual characteristics, such as case, font, size, and length, which means that it takes only the relevant information from the stimuli (invariance characteristic). For example, this area recognizes TABLE, table, tAbLe, and *table* as the same word. It is also insensitive to orthographic regularity (activating equally for regular and irregular words). These characteristics allow the VWFA to support easy, fast, effortless, and automatic word recognition in literate individuals.

2.3.1.1 The Visual Word Form Area in literate, illiterate, and neoliterate adults. Dehaene et al. (2010) conducted an fMRI study, contrasting participants who were illiterate, neoliterate, and literate, to explore how literacy changes cortical networks for vision. Participants were scanned while looking at blocks of faces, houses, tools, letter strings, false-font strings, and moving checkerboards. To maintain attention, participants were asked to press a button if they saw a star-shaped stimulus. When comparing activation data, literate and neoliterate participants showed stronger left occipito-temporal activation in response to letter strings than for the other stimulus types, but this distinction was not seen in illiterate participants. This suggests that late literacy training is sufficient to develop activation in the Visual Word Form Area. However, it remains the case that late literacy acquisition appears to result in different brain reorganization than that observed for people who learned to read as children (Castro-Caldas et al., 1998, 1999; Castro-Caldas & Reis, 2000; Ostroski-Solís et al., 2004). Evidence for this comes from fMRI results obtained using a different task from the same study, in which participants had to read sentences serially presented on a screen. Neoliterate participants showed greater activations than literate participants in the bilateral medial fusiform area and right posterior parietal cortex. The authors suggested that neoliterate participants could be using a broader network than literate participants, increasing the need to recruit additional posterior parietal regions, associated with serial effortful reading to be able to perform the task (Dehaene et al., 2010). Even though activation differences between literate and neoliterate adults were evidenced by the recruitment of broader areas to perform word recognition tasks, this study showed that learning to read has an impact on brain organization regardless of when the skill is acquired. In conclusion, the authors proposed that there are three ways in which literacy changes brain organization: (1) there is an enhanced response to familiar orthographic script in the VWFA in left occipito-temporal cortex, and occipital cortex in general; (2) language networks usually become active during sentence reading; and (3) reading "supports" spoken language by enhancing activation in regions associated with phonological processing (such as the planum temporale), allowing orthographic processes to be accessed in a top-down manner.

To summarize, studies using eye-tracking and other techniques have shown that fluent readers fixate on a written word in text for approximately 200 to 300 milliseconds, indicating that the information needed for word recognition is obtained in this time window (Rayner, 1998). Given these findings, the neural processing attributed to the VWFA should occur in the vicinity of 200 milliseconds post stimulus onset (Maurer &

McCandliss, 2007). Behavioral responses, such as reaction time and accuracy, provide information about the outcome of a given task after many processes have occurred but cannot offer insights into the processes that are taking place in the brain while reading is occurring (Bentin et al., 1999). Hemodynamic/metabolic imaging techniques, such as fMRI and PET, have precise spatial resolution but lack the temporal resolution needed for differentiating early perceptual processes from late post-perceptual processes, which are crucial to exploring automaticity in reading activity (Schlaggar & McCandliss, 2007). Exploration of brain activity through the use of EEG methods offers a complementary method, furthering investigation of the VWFA, adding the possibility of contributing essential information about the temporal dimension of brain activity in this area of the brain thought to be so critical to fluent automatic reading. The EEG technique allows the isolation of the time period in which perceptual processes take place, thus permitting the possible identification of those processes that index fast word recognition. The N170 ERP is a prime candidate for elucidating reading expertise. A review of investigations of the N170 ERP component follows.

2.1.4 ERP component N170

The N170 event-related potential (ERP) is a negative deflection obtained from the EEG recording that occurs at about 170 milliseconds post-stimulus presentation. This component is commonly elicited by visual stimuli from many categories, such as objects and faces, and it reflects expertise or automaticity in visual recognition processes (Tanaka & Curran, 2001). It is generated in the bilateral occipito-temporal region of the brain, a visual association area of the cortex known to be related to object recognition (Grill-Spector, 2003).

Visual recognition of words is represented differently in the brain when compared to object or face recognition. Face and object recognition elicit bilateral N170 activation (Itier & Taylor, 2004). However N170 activation for words and word-like stimuli (pseudowords, consonant strings, or non-words) tends to be more left lateralized than other lower-order visual stimuli (dots, stars, or checkerboards) (Bentin et al., 1999; Brem et al., 2005; Maurer, Brandeis, & McCandliss, 2005; Maurer, Brem, Bucher, & Brandeis, 2005; Tarkiainen, Helenius, Hansen, Cornelissen, & Salmelin, 1999; Zhang, Begleiter, Porjesz, & Litke, 1997). Source analysis of a reading-related N170 shows that the main generators of this activation are in left inferior occipito-temporal cortex (Maurer, Brem, et al. 2005; Michel et al., 2001; Rossion, Gauthier, Goffaux, Tarr, & Crommelinck 2002), the area Cohen et al. (2000) named as the Visual Word Form Area.

There are three main characteristics of the left-lateralized N170 associated with reading and the visual process of linguistic information: (1) it is related to language; (2) it reflects expertise or familiarity with a stimulus; and (3) it signifies automaticity of processing. Each of these features is explored below.

The relationship of the left N170 to language has been established in studies in which words and word-like stimuli elicited a left-lateralized N170 compared to a bilateral or right-lateralized N170 for other non-linguistic stimuli. This phenomenon is explained by the Phonological Mapping Hypothesis (Maurer & McCandliss, 2007). According to this hypothesis**,** reading consists of the transformation of visual information (graphemes) into aspects of oral language (phonemes). Since the left hemisphere is involved in language processing, the grapheme-phoneme conversion processing indexed by the N170 is related to neural systems in the language regions of the brain. However, processing of non-linguistic symbols is handled by the right hemisphere, which is specialized more for visuo-spatial processing, or bilaterally.

Response patterns have established that with high frequency words, the N170 amplitude decreases, which likely indicates expertise. This means that familiar words require less activation, resulting in a more efficient processing of visual input (Assadollahi & Pulvermüller, 2003; Hauk & Pulvermüller, 2003; Sereno, Brewer, & O'Donnell, 2003).

Additionally, left N170 activation is thought to be an index of automaticity in the visual processing of words, since it can be elicited even when subjects are not aware of the recognition task, indicating that no attention is required to process the visual stimulus (Bentin et al., 1999; Brem et al., 2005; Maurer, Brandeis, & McCandliss, 2005; Maurer, Brem et al., 2005; Maurer & McCandliss, 2007; Tarkiainen et al., 1999). One of the most effective ways to elicit the reading-related and automatic N170 component is by using a one-back paradigm (Gevins & Cutillo, 1993). This is a task in which participants are asked to watch a series of visual stimuli and press a button whenever an immediate repetition occurs. By the use of linguistic (words) and non-linguistic (symbol strings) series of stimuli, researchers can identify the neural underpinnings of automatic processing of both (linguistic and non-linguistic) types of information. Note that the response to a one-back task is considered to be automatic, since the participant is not asked to read or conduct any special analysis of the stimulus, just watch for a repetition. By simply engaging visual processes, the task can be performed successfully. The idea behind this is that if the participant shows a left occipito-temporal activation for the word stimulus (linguistic), reading automaticity can be inferred. This is because, even without being asked to consciously read, the participants are recognizing the stimulus as something related to language (under the phonological mapping hypothesis). In other words, reading for the automatic reader is unavoidable.

The experimental setup to elicit a reading-related N170 is crucial for the current study; therefore, it will be described in detail in the following sections, alongside consideration of other factors relevant to the current study: (1) the development of reading expertise; (2) the relationship between N170 and orthographic consistencies; and (3) the relationship between N170 and learning a new script as an adult.

2.1.4.1 N170 and the development of reading expertise. Maurer, Brandeis, and McCandliss (2005) studied a group of 29 pre-literate children, mean age 6.5 (SD = 0.38), using a one-back paradigm. Participants were asked to detect immediate repetitions of visually presented blocks of words and symbols. The researchers divided their sample into groups of children with low letter-knowledge and high-letter knowledge. Children with low-letter knowledge did not show differences in the amplitude of N170 for words and symbols. This means that both words and symbols were being processed as similar visual objects (evidenced by the same amplitude) and there was no special language-related feature developed for word stimuli (since no significant effects were found on the left hemisphere). Conversely, children with high letter knowledge showed greater N170 amplitude in response to written words than to symbols, with main effects observable over the right hemisphere of the brain. Greater activation in response to words than to symbols over the right hemisphere is thought to indicate some sort of familiarization effect for words, but not linguistic processing per se – similar to what occurs when a person becomes familiar with the logo of a popular brand.

Maurer et al. (2006) assessed the reading-related N170 on a group of 20 typically developing second graders by asking them to perform a one-back paradigm. They found that the N170 activation for words was stronger for symbols. This suggests emerging expertise for word-like stimuli. The effect was seen in both the left and right hemispheres, reflecting more left hemisphere involvement as expertise develops, while conserving right hemisphere activation from previous stages (like the participants reported on by Maurer, Brandeis & McCandliss, 2005). By contrast, literate adults show larger N170 amplitude for words than symbols over left hemisphere sites only, reflecting activation in regions that are specific to language processing (Maurer, Brandeis, & McCandliss, 2005). This, according to the authors, represents mature reading expertise.

In summary, developmental studies on N170 have described how N170 activation shifts from the right to the left hemisphere after a person is exposed to reading instruction. For pre-literate children, activation for any type of visual stimuli is the same, and there is no left-hemisphere dominance, indicating that no expertise has been developed (Maurer, Brandeis, & McCandliss, 2005). Children with high-letter knowledge show evidence of a slight emerging specialization, supported by the observation of larger N170 amplitudes for words than for symbols, but in the right hemisphere (Maurer, Brandeis, & McCandliss, 2005). This has been described as a “familiarization” effect. When children finish their literacy training, in second grade, they show larger N170 amplitudes for words than symbols bilaterally (Maurer et al., 2006). And finally, when literacy has been acquired and automatized, N170 activation is larger for words than for symbols, in the left occipito-temporal cortex, indicating that word stimuli are perceptually processed as language-related stimuli.

2.1.4.2 N170 in languages of different orthographic consistencies. N170 visual specialization for reading was explored in two studies of languages that differ in their orthographic consistency. The first study was conducted in German, which has a transparent orthography (Maurer, Brandeis, & McCandliss, 2005), and the second one in English, which has an opaque orthography (Maurer, Brem, et al., 2005). Consistency of grapheme-phoneme conversion is what determines whether the orthography from a particular language is considered transparent or opaque. Orthographies with clear grapheme-phoneme conversion are considered transparent; and orthographies with more ambiguous rules are considered opaque (Ellis et al., 2004).

Both studies used healthy adults who learned to read and write in childhood. In both studies, participants were asked to watch blocks of serially presented words, pseudowords, and pictures. They were instructed to press a button whenever they saw an immediate repetition of a stimulus – a "one-back" paradigm. Data were analyzed by comparing N170 amplitude, global field power, and topography. The results for both studies were similar with respect to the word vs. symbol contrast. N170 amplitude was greater in response to words than symbols over the left occipito-temporal electrodes. In the topographical analysis, words and symbols were seen to involve two different topographies. Negative fields over the posterior part of the scalp were most pronounced at inferior sites for words and superior sites for symbols. This strongly suggests that linguistic and non-linguistic visual information are processed by different neural networks in the brain and that this effect does not depend on orthographic consistency within the language.

On the other hand, these studies did reveal differences on the word vs. pseudoword contrast between the German and English participants. English participants showed more left-lateralized N170 activations for words than for pseudowords, whereas German participants showed left lateralization in response to both words and pseudowords. The authors concluded that, since German is a more transparent orthography, the left-lateralization for words was generalized to pseudowords, because both can be easily decoded by means of grapheme-phoneme conversion or (by analogy) via the lexico-semantic route. In transparent orthographies, novel words and pseudowords can be easily converted for reading, with few errors. However, in a more opaque orthography, like English, pseudowords represent a more ambiguous category, since there are many ways in which they can be read. Therefore, the left-lateralized N170 response to written words does not generalize to pseudowords in a language like English.

To avoid this ambiguity, the current study examined participants whose main language is Spanish.

2.1.4.3 N170 in learning a new script. In a study by Maurer, Blau, Yoncheva, and McCandliss (2010), 20 participants (mean age 25) were trained to read an artificial script. Half of them were taught to recognize whole "words," while the rest were taught to use grapheme-phoneme conversions to "spell out" the words. The experimental task was a one-back paradigm, consisting of the presentation of a series of stimuli, in which participants had to press a button whenever a stimulus was repeated twice in a row (Maurer & McCandliss, 2007). The stimuli consisted of artificial words, real words, and symbols. Note that a one-back task does not require reading, simply repetition detection. A visual feature analysis of the stimuli suffices to perform this task. However, if the person is a fluent reader and a word is presented, reading is unavoidable; in this case, a left-lateralized N170 would be observed, indicating automaticity. In this study, the N170 effect was found over the right hemisphere for both groups. This suggests that grapheme-phoneme conversion had not yet been automatized after the initial learning of an artificial script, but that there was a familiarization effect, shown by the right hemisphere activation. This is similar to the N170 effects previously observed in pre-literate children (Maurer, Brandeis, & McCandliss, 2005).

Yoncheva, Blau, Maurer, and McCandliss (2010) tested the same participants from Maurer et al.'s (2010) study to examine whether or not the method of instruction (whole word reading vs. grapheme-phoneme conversion) impacted the N170 effects. They used a reading dependent paradigm called a "reading verification task" that consists of the presentation of a written word, followed by an auditory word. The participants had to identify whether or not the visual and auditory words matched. This task does involve reading, unlike the one-back paradigm, since the participants must decode the phonological representation of the visually presented word in order to make a comparison between it and the auditory word. The authors selected this task to make sure that participants were in fact consciously using the reading strategies learned during training, since they could not perform the task by analyzing visual features only. The group that was trained on grapheme-phoneme conversion strategies showed a left-lateralized N170 response to this task. This was interpreted as evidence that grapheme-phoneme conversion rules were used. On the other hand, the group that was trained on whole word reading showed a right lateralized N170, which suggested that the link between graphemes and phonemes was not yet established.

N170 is a task-dependent component (Dien, 2010). This means that its interpretation is subject to the type of activity the participant is asked to perform. For example, if the reading task consists of asking the participants to watch written words, but not to read them, then the left-lateralized N170 evoked by these words could index automaticity of visual word processing. Visual word recognition is taking place in the brain, even when the participants are not consciously reading, because reading happens automatically – that is, without conscious control. On the other hand, if reading tasks force the participants to read consciously, as in the paradigm used by Yoncheva et al. (2010), N170 effects would index visual word recognition, but not automaticity, since the attentional resources are focused on the reading task.

This chapter provided an overview of the theories of word recognition, and its neural underpinnings. In the next chapter, I will describe the study hypotheses, and show how they are derived from the theoretical and experimental frameworks considered so far.

Chapter III

HYPOTHESES

The purpose of this study is to explore the ERP component N170 as an index of a visual word specialization in Spanish-speaking neoliterate adults, compared to Spanish-speaking literate adults who learned to read during childhood. It is important to study word specialization in adults who are neoliterates, since people who learn to read as adults tend to read slowly and with a great deal of effort. In other words, they are not automatic readers (Abadzi, 2003a, 2003b), implying that this early process might not be fully developed. The study of word reading automaticity using behavioral measures is challenging, since word recognition occurs within the first 200-250 milliseconds (Sereno & Rayner, 2003), and because there is a possibility to have the same behavioral response from the activation of different brain networks.

The short latency of the ERP component N170 (less than 200 milliseconds) makes this component suitable to explore very fast and somewhat unconscious processes such as automatic word recognition.

What differentiates reading-related N170 from other visual N170 is its lateralization. Linguistic stimuli (usually words) tend to elicit a left lateralized N170 because the left hemisphere is usually dominant for language. Conversely, other types of visual stimuli elicit right or bilateral activation. This means that very early on (200 milliseconds), the brain recognizes print as language. According to Maurer and McCandliss (2007), this ability to assume that print is language, is due to great amount of exposure to print, and continuous and extensive training in reading.

Investigating the N170 component might allow for exploration of how the brain responds to learning to read later in life. It would provide evidence of whether adults who are neoliterates present a similar pattern to children who recently learned, implying a possible automaticity of word recognition.

Automaticity of word recognition was targeted by manipulating the focus of attention to different linguistic features during two reading tasks: (1) a one back-paradigm (similar to Maurer et al., 2010), and (2) a reading verification task (similar to Yoncheva et al., 2010). In the one back paradigm, participants were asked to watch words and symbols and press a button when they observed an immediate repetition. The focus of attention in this task was the visual word form, not necessarily reading; therefore, the data obtained by contrasting brain responses to the words vs. symbols would indicate possible reading processes that are occurring without conscious awareness, in other words, automatically. In the reading verification task, participants were asked to read and listen to words and decide whether or not they match. This task requires reading the words, automatically or intentionally, for all participants.

The following are the two main research questions, and related hypotheses, for this study that were answered using the neurophysiological measures:

(a) Do adults who are neoliterate (study group) show evidence of ***automatic*** word recognition indexed by eliciting reading-related brain activity in tasks that do not necessarily require reading, as seen in adults who are expert readers (comparison group)?

HYPOTHESIS A: The control group is predicted to show a left-lateralized N170 effect (words elicit larger amplitude than symbols on the left occipito-temporal region) in a one-back paradigm, while the study group is expected to not show the left-lateralized N170 effect. This would reflect automaticity of the grapheme-phoneme conversion process for the control group, and not for the study group.

(b) Do adults who are neoliterate (study group) show evidence of ***intentional*** word recognition indexed by eliciting reading-related brain activity in tasks that require reading, as seen in adults who are expert readers (comparison group)?

HYPOTHESIS B: We expect both groups to show greater amplitude for the N170 over the left occipito-temporal region than the right occipito-temporal region. This would be evidence of an emergent left occipito-temporal specialization for word stimuli, but apparent only when grapheme-phoneme conversions are brought to the conscious level, when forcing the participants to read.

Chapter IV

RESEARCH DESIGNS AND METHODS

This study was designed to investigate the hypothesis about the difficulties of reading automaticity acquisition in adult neoliterates. It will use both behavioral (accuracy and reaction time), and neurophysiological methods to do so. Automaticity in reading cannot be directly evaluated from behavioral measures alone, since this process occurs within milliseconds, and behavioral responses take a couple of seconds to emerge. Therefore, the study makes use of EEG, which is a non-invasive technique for recording electrical activity related to intracellular communication in the brain. The signal is a collection of synaptic activity from a large group of cells, particularly pyramidal cells (Öllinger, 2009). The synaptic potentials that can be measured using EEG scalp electrodes come primarily from the thalamo-cortical pathways. EEG detects voltage variations through electrodes that are placed on the surface of the scalp at specified locations and provide high temporal resolution, but source estimates for the observed electrical activity are less precise, due to smearing and distortion of the signal (Handy, 2005). The recorded voltage variations are expressed as positive and negative deflections relative to a reference electrode. By segmenting and averaging the recorded voltages, time-locked to a specific stimulus or event, it is possible to derive event-related potentials (ERPs) from the EEG recordings (Rugg & Coles, 1995). ERPs reflect electrophysiological responses that are associated with internal or external stimuli, and are used to provide information about the neurophysiological underpinnings of processes and constructs that have been proposed by cognitive psychology (Öllinger, 2009). By presenting multiple fixed events to the participant during continuous EEG recording, and then averaging the recorded signal related to the event, it is assumed that the resulting ERP is related to the brain activity that occurs as part of the brain's response to that particular event type (Handy, 2005). In this chapter, specifics of the research design will be provided, including EEG recording methods and parameters.

4.1 Design

Two experiments were conducted in this study, both of them following a 2 X 2 mixed experimental design. This allows the comparison of brain activity within the same participants and comparisons between the two groups. The first experiment explored brain activation during two processes: one that is related to implicit or unconscious single word reading, and the other to the implicit or unconscious processing of non-linguistic visual stimuli. These processes were elicited by asking the participants to look at single words and at symbol strings, respectively. The second experiment attempted to explore brain activity during conscious reading. This was elicited by asking the participant to detect whether or not visual and auditory words matched.

2 X 2 Experimental Design:

	Experiment 1	**Experiment 2**
Stimuli	words vs. symbols	matched vs. unmatched
Groups	literate vs. neoliterate	literate vs. neoliterate

4.2 Materials

The materials for this study consisted of two main parts: (1) instruments to determine eligibility for the study, and (2) the neurophysiological experiments.

4.2.1 Instruments to Determine Eligibility for the Study

4.2.1.1 Background questionnaire. This was conducted to obtain general demographic information, immigration information, language information, and education information (see Appendix A).

4.2.1.2 Phonological awareness test – Prueba de la Evaluación del Conocimiento Fonológico (Ramos Sánchez & Cuadrado Gordillo, 2006). Phonological awareness is both needed and enhanced by literacy (Hogan, Catts, & Little, 2005). Therefore, information about each participant’s phonological awareness for their native language was required. In addition, the N170 component for word recognition is partially accounted for under the Phonological Mapping Hypothesis (Maurer & McCandliss 2007). This test assesses the ability to identify and consciously manipulate syllables and phonemes in words, thus indicating each person's degree of skill with phonological mapping. It consists of six tasks organized in two phonological awareness levels (syllabic and phonemic), tested in three different tasks (identification, addition, and omission). Scoring consists of assigning one point per correct response. An example of each task is provided in the appendices (see Appendix B).

4.2.1.3 Working memory test – Spatial Span subtest from Wechsler Memory Scale III (Wechsler, 1997). Both neurophysiological experiments (one-back paradigm and reading verification task, explained further below) rely on working memory. We conducted a working memory test on all participants to validate that they had similar abilities in this domain. Spatial Span was chosen because the task does not depend on literacy, evidenced by similar task performance by both literate and illiterate individuals (e.g., Kosmidis, Zafiri, & Politimou, 2011; Silva, Faísca, Ingvar, Petersson, & Reis, 2012). Kosmidis et al. (2011) assert that the cognitive skills needed for the spatial span task do not necessarily get trained in school but can be developed in everyday life, since this kind of memory and retrieval task is relevant for many typical activities. In addition, Silva et al. (2012) suggest that using three-dimensional figures to conduct working memory tests could be more appropriate for groups that vary in reading ability, since learning to read may have an impact on processing of two-dimensional images.

The Spatial Span subtest consists of an array of 10 three-dimensional blocks located on a board. The researcher taps increasing numbers of blocks in a predetermined order, and the participant has to repeat the same pattern. This task was conducted in the forward version (in which participants had to repeat the same sequence), and backwards (in which participants were asked to repeat the sequence from end to beginning). Scoring for this task is the total number of correct trials before failing two consecutive trials (see Appendix C).

4.2.3.4 Word recognition test in Spanish – Letter and Word Identification from Woodcock Muñoz III. The purpose of this test was to assess the recognition of visual word forms in the participants' first language, Spanish. This was conducted to confirm that both groups were able to read. The suggested scoring method assigns one point per fluently recognized word. Since reading automaticity is not assumed in the studied population, in addition to the fluency score, we created a second score (the effortful reading score), in which participants would receive one point per correct response, regardless of how fast or slow they read (see Appendix D).

4.2.3.5 Word recognition test in English – Letter and Word Identification from Woodcock Johnson III. The participants from this group do not speak English but have been living in the United States for some years; therefore, they have been exposed to English printed words. The purpose of this test was to quantify how much they know about English words, and whether this had an impact in their first language literacy acquisition. As for the Spanish word recognition test, the suggested scoring method assigns one point per fluently recognized word. This test was therefore also scored with the second score (the effortful reading score) in which, as described above, participants would receive one point per correct response, regardless of how fast or slow they read (see Appendix E).

4.2.3 Neurophysiological Experiments

Two EEG experiments were conducted.

4.2.3.1 One-back paradigm. This is an implicit reading task, since participants were not asked to read consciously. They were asked to watch blocks of words and symbols, and to press a button whenever an immediate repetition occurred. The words and symbols were presented in the middle of a white screen using black font. One hundred forty-four high frequency words and 144 symbol strings were presented in eight blocks of 36 stimuli. Seventeen percent of the stimuli were immediately repeated. The stimuli were presented for 700 milliseconds, followed by an interstimulus interval (ITI) of 500 milliseconds on average (ranging between 300-700 milliseconds). Behavioral responses (accuracy and reaction time) and neurophysiological responses (continuous EEG) to both words and symbol strings were collected.

The word stimuli were obtained from the Spanish word frequency and orthographic neighborhood database developed by Pérez, Alameda, and Cuesto Vegas (2003). The 144 words were nouns that contained from 4 to 6 letters (mean = 4.833; SD = 0.69), and were of high lexical frequency (mean = 121 per million words found in text; SD = 94) (See Appendix F for a list of words).

The symbol stimuli were created based on the shapes developed by Maurer, Brandeis, and McCandliss (2005) and Maurer, Brem, et al. (2005) (see Appendix G for a complete view of the symbols). They were first designed in Adobe Photoshop image processing software and then transferred to FontCreator, software that converts small images into fonts. The decision to present symbol stimuli as fonts, and not images, was made because the timing of presentation between fonts and images could vary (given constraints of the stimulus presentation software used for EEG experimentation), and stimulus timing precision is crucial in EEG research. Therefore, symbol fonts for the symbol stimuli were created to match the alphabetic fonts used in the word stimuli. The symbols were matched to some features of real letters, especially the fact that letters have features such as desce ders and ascenders. This was controlled so as to maintain the same print space between words and symbols. Three of the originally created symbols were discarded since they looked very similar to real letters, and this could impact the results. Our symbol fonts compared to alphabetic fonts were thinner, so we chose the **bold** option for the symbol setup to make sure both alphabetic and symbol fonts matched. Examples of the experimental trials in the one-back paradigm are shown in figure 6 below.

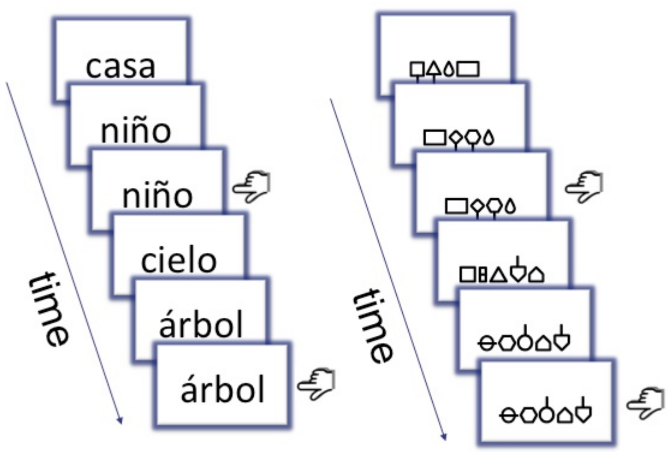


Figure 6: One back paradigm

Participants were asked to press a button whenever an immediate repetition occurred. As shown in Figure 6, stimuli are real words (left) and symbol strings (right), presented in separate blocks.

4.2.3.2 Reading verification task. This is an explicit reading task, since participants had to read (not only recognize visual stimuli) in order to successfully perform the task. Participants were asked to determine whether a written and an auditory word matched. They were instructed to press one button if the words matched and a different button if the words did not match. One hundred forty-four written words paired with 144 auditory words were presented in 4 blocks of 36 stimuli. The visual and auditory word stimuli were obtained from the Spanish word frequency and orthographic neighborhood database developed by Pérez, Alameda, and Cuesto Vegas (2003). Words were nouns from 4-6 letters in length (mean = 4.75; SD = 0.66), and of high lexical frequency (mean = 107 per million words found in text; SD = 83) (See Appendix H for a list of words). The visual stimuli were presented in the middle of a white screen using black font. The auditory stimuli were presented binaurally (through earphones) at 60 dB. The written and auditory words matched 50% of the time. Each trial began with a fixation point that was presented for 700 milliseconds, followed by the written word that remained visible until the end of the trial. Eight hundred milliseconds after the visual word presentation, the auditory word was presented. Behavioral responses (accuracy and reaction time) and neurophysiological responses (continuous EEG) were recorded. Figure 7 depicts the timeline for the reading verification task.

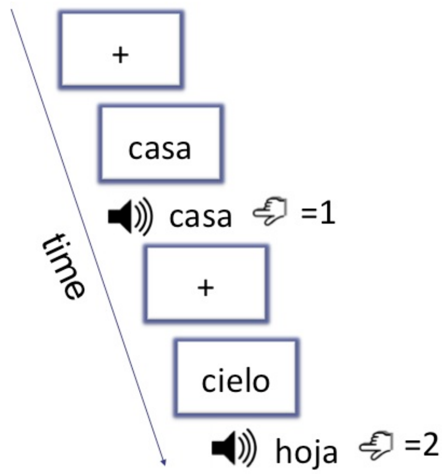


Figure 7: Reading verification task

Participants were seated at a desk that held a response box (more information below); they were asked to press button 1 on the response box if the words they heard and saw were the same, and button 2 if they were different.

4.3 Participants

Two groups of adults were recruited for this study: a study group of adults who for social reasons did not go to school in childhood, and who were about to finish a literacy training; and a comparison group of adults who had learned to read in childhood. Participants from both groups reported no history of learning disability, language disorder, or brain damage, as inquired on the background questionnaire. They were Spanish-speaking immigrants from different countries in Latin America. Even though all had been living in New York for about 10 years, their English knowledge was limited. Specific characteristics of each group are described below.

4.3.1 Study Group

The study group consisted of 8 participants (4 males, 4 females), mean age = 39.88; SD = 8.6, who have been in the United States for a mean of 14.6 years, SD = 2.92, recruited from an adult literacy institution in Manhattan, NY. They reported to have left school for family reasons (losing parents, parents could not afford to send them to school, parents did not want them to go to school, there were no schools in their neighborhood). At the time of the data collection, they were about to complete a 2-year literacy training in a community center in Manhattan. Their mean self-reported English proficiency is 0.5 (0 being the worst score, and 3 the best score). Mean score for Spanish word recognition (Woodcock-Muñoz letter and word recognition subtest) was 21.88 for fluent word recognition, SD = 4.6 (equivalent to 1st grade); and 58.38 for effortful word recognition, SD = 10.7 (equivalent to 7th grade). The mean score for English word recognition (Woodcock-Johnson Letter and Word Recognition subtest) was 13.75 for both fluent and effortful word recognition, SD = 5.8 (equivalent to kindergarten). The mean score for phonological awareness was 15.75, SD = 1.8 (equivalent to low phonological awareness skill). Finally, the mean score for visuo-spatial working memory was 11.88, SD = 2.9, similar to what was found on the comparison group.

4.3.2 Comparison Group

The comparison group consisted of 8 participants (3 female, 5male), mean age = 48.9, SD = 11.44, who have been in the United States for a mean of 13.86 years, SD = 13.6. They were recruited from the local community by invitation. Five of them had finished high school, and three had started the first semester in college. Their mean self-reported English proficiency is 0.7 (0 being the worst score, and 3 being the best score). Their mean score for Spanish word recognition (Woodcock-Muñoz letter and word recognition subtest) was 74.5 for both fluent word recognition and effortful word recognition, SD = 1.8 (equivalent to more than 18 years of schooling). The mean score for English word recognition (Woodcock-Johnson letter and word recognition subtest) was 31.87 for both fluent and effortful word recognition, SD = 13 (equivalent to 7th grade). The mean score for phonological awareness was 26.38, SD = 2.5 (equivalent to high phonological awareness skill). Finally, the mean score for visuo-spatial working memory was 11.88, SD = 2 (similar to what was found on the study group).

A table with individual information of participants is provided in the Appendices (Appendix I).

4.4 Experimental Procedure

The experiment was performed in accordance with the requirements of the Institutional Review Board for the Protection of Human Subjects at Teachers College, Columbia University. Participants were given a tour of the lab, including a viewing of the sound attenuated room where they sat during the EEG recordings. They were informed that they could withdraw from participation at any time during the course of the experiment, without any penalty. Every step of the procedure was explained and discussed as it occurred, and there was ample opportunity for the participants to ask questions or to express concerns or anxieties. All participants were encouraged to ask questions, and all were told that if they felt tired or simply wished not to continue at the time, or if they wished to withdraw temporarily to rethink their participation, they could reschedule or cancel their appointment (no participants requested to withdraw or delay their participation, however.) Since this population consisted of people that might or might not have good reading comprehension, the researcher read a summary of the consent form aloud. Then a set of yes/no questions was asked to the participants to check if they understood the process, and finally they signed the form. All consents and other forms were presented in the same manner to each participant at each session (see Appendix J). Finally, all participants were provided with a telephone number and email address to contact the researcher should any questions or concerns arise at any time subsequent to their participation.

Having provided informed consent and demonstrated understanding of their participation in the study, all participants experienced the experimental procedure in the following sequence.

(i) Administration of background questionnaire.

(ii) Administration of word recognition tests in Spanish and English (Woodcock Johnson, and Woodcock Muñoz. respectively).

(iii) Administration of phonological awareness test in Spanish.

(iv) Administration of working memory test.

(v) Practice run: The researcher explained the tasks for both conditions, and participants had an opportunity to practice similar trials on the practice computer. The practice task contained runs of 5 one-back stimuli and 5 reading verification stimuli.

(vi) Measurement of head size and vertex location: The circumference of each participant's head was measured to ensure the correct size sensor net was selected, and their vertex marked to guarantee accurate placement of the net.

(vii) Participants were fitted with an appropriate 128-channel HydroCel Geodesic Sensor Net (HCGSN) (Net Amps200, Electric Geodesics Inc., Eugene, OR) with electrodes referred to the vertex. These nets are arrangements of electrodes, held in relative positions to each other with fine elastic. The electrodes, embedded in sponges, were soaked in a weak electrolyte solution (potassium chloride). The geodesic sensor net is quick to apply and comfortable to wear and does not require scalp abradement or the application of any electrode glue. Once the sensor net was applied to the participant, the sensors were adjusted so that they were in good contact with the scalp. The net was connected to a high-input impedance amplifier (Net Amps200, Electric Geodesics Inc., Eugene, OR). The amplified analog voltage (0.1-100 Hz bandpass) was digitized at 250 Hz. The individual sensors were adjusted to maintain impedances less than 40kΩ, and the electrodes were referenced to the vertex during the recording. In order to identify eye movement artifacts, sensors were placed above and below the eyes and at the outer canthi.

(viii) EEG recording: Participants were seated on a chair in a sound attenuated chamber within the lab. The amplifier was checked and calibrated before the net was connected, and impedances (loss of signal between scalp and sensor) were measured by feeding a minute (400 microvolt) electrical field through each electrode, which was then “read back” by the acquisition system so that the amount of signal loss could be calculated. A response button box was provided for the participant to indicate the response to each trial presentation. The participant was asked to complete the one-back paradigm and the reading verification task.

(ix) After net removal and an opportunity for debriefing, participants were given an envelope with $25 cash and a round-trip Metrocard to thank them for their time, and they were escorted from the building.

(x) To prepare the recorded data for analysis, detailed in Chapter V, all recordings were transferred from the data acquisition computer to a secure server and converted into the required format. The details of the data analysis are provided in the next chapter.

Chapter V

DATA PRE-PROCESSING AND ANALYSIS

5.1 Data Pre-processing

A standard ERP analysis protocol was followed for the analysis of the EEG data (following principles described in detail in Handy, 2005; Luck, 2005; Picton et al., 2000). The recorded raw EEG data were digitally filtered offline using a 30 Hz Low Pass filter, and then subject to automatic and manual artifact rejection protocols for removal of movement and physiological artifacts (EKG, EMG, EOG). Noisy channels were marked as bad and interpolated using spherical spline modeling, based on recorded data from surrounding sensors. Data were re-referenced to an average reference to eliminate the influence of an arbitrary recording reference channel (and also to permit inclusion of the vertex electrode in data analysis). Average referencing in EEG uses the average of all of the recorded channels to better approximate the ideal zero reference values, and is an appropriate procedure for sensor arrays of greater than 64 channels (Handy, 2005; Luck, 2005; Picton et al., 2000). To examine the EEG waveform for ERP components following onset of the words or symbols, the continuous recording was segmented into 1000 millisecond epochs, including 200 milliseconds pre-stimulus (the "baseline period") and 800 milliseconds post-stimulus.

Segments of EEG data that were associated with stimuli from the same experimental conditions were averaged together to reduce the influence of random noise, and to permit identification of time-locked event-related responses associated with the onset of the words or symbols. EEG epochs were averaged separately for congruent trials and incongruent trials for each condition, for each individual participant. Then, the averaged waveforms were baseline-corrected to control for drift. Baseline correction procedures involve using the average electrical potential during the 200-millisecond baseline period to calculate a mean measure of background activation, which is then subtracted from the recorded activity after the onset of the stimulus. This has the effect of approximating data more closely to zero and therefore constitutes an important noise reduction measure (Handy, 2005; Luck, 2005). Finally, two montages were applied to the data in order to examine the different responses by electrodes in specific areas of the scalp. The two montages applied to these data correspond with the left posterior occipital (electrodes 51, 52, 57, 58, 59, 60, 63, 64, 65, 66, 68, 69, 70 from the hydrocel net) and the right posterior occipital regions (electrodes 83, 84, 85, 89, 90, 91, 92, 94, 95, 96, 97, 99, 100 from the hydrocel net). The regional montages are shown in Figure 8 below, as blocks of differently colored electrodes:

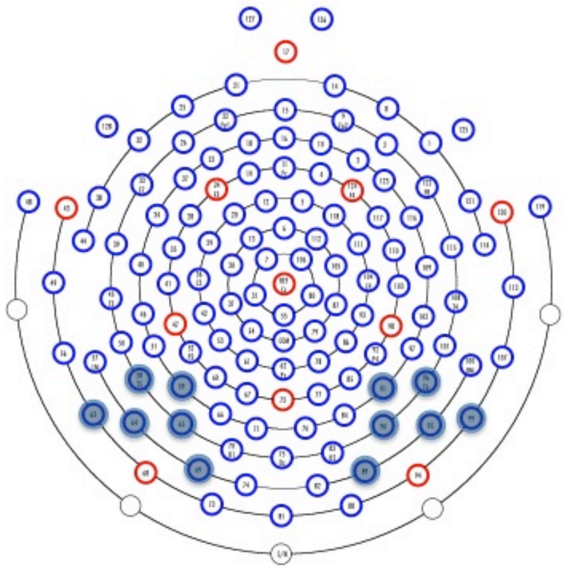


Figure 8: Left and Right Occipito-temporal montages

This diagram represents electrode placement position on the scalp. The top of the image represents anterior scalp locations, and the bottom, the posterior scalp locations.

The montaged data were exported in a format permitting further analyses using data analysis packages, including MATLAB and SPSS.

Following processing of data from individual participants, as described, individual averages were later grand-averaged together (Luck, 2005; Picton et al., 2000). This enabled us (in a pilot version of the study) to identify the predicted ERP components for the one-back and reading verification conditions by comparing waveforms obtained in response to words and symbols (for the one back condition), and left and right montages (from the reading verification task).

5.2 Data Analysis

5.2.1 Behavioral Data Analysis

Accuracy was calculated by counting the proportion of correct responses from the total responses in the conditions. Reaction time is the time elapsed (in milliseconds) from the moment the target stimulus is presented to collection of the button-press response. The times obtained for incorrect button responses (error trials) were omitted from the analysis. If no button response was detected when expected, the trial was considered a "time-out"; therefore, the value of it would be 800 milliseconds, the whole epoch. Time-outs were also counted as error trials and excluded from further analysis. Arcsine accuracy and log reaction time were calculated, and used in further analyses as a method for correction to normality.

For the one-back paradigm, accuracy and reaction time were analyzed using a two-way mixed ANOVA with group (study vs. comparison) and stimuli (word vs. symbol).

For the reading verification task, accuracy and reaction time were analyzed by using a two-way mixed ANOVA with group (study vs. comparison) and stimulus type (words that match vs. words that do not match). The same analysis was conducted for reaction time.

5.2.2 Neurophysiological Data Analysis

N170 peak amplitudes were identified by measuring the waveform, in microvolts, at the time point where the component of interest reached its maximum (or minimum) for each participant (Handy, 2005). This type of analysis is recommended for well-identified peaks, such as the N170. For the one-back paradigm, a three-way mixed ANOVA, with two groups (study vs. comparison), two levels of region (left occipito-temporal vs. right occipito-temporal), and two levels of stimuli (words vs. symbols) was conducted. The reading verification task analysis consisted of a two-way mixed ANOVA, with two groups (study vs. comparison) and regions (left occipito-temporal vs. right occipito-temporal). Since this study in concerned about automaticity, and behavioral responses occur after 200 milliseconds, all accurate and inaccurate behavioral responses will be part of the analysis.

Post-hoc analyses exploring activation outside of the N170 timing range (200-600 milliseconds post stimuli) and outside of its expected region were conducted with mean amplitude as the dependent variable. Mean amplitude is derived by calculating the mean of the recorded data points within the time window in which the component of interest is expected to occur. It is recommended for components that do not have well-identified peaks, or when there are no a priori hypotheses (Handy, 2005). Since all the a priori hypotheses for this study concerned the N170, it was appropriate to use a mean amplitude measure for post hoc analyses that examined brain responses outside the target time window.

Behavioral responses (accuracy and reaction times) were organized and processed using Excel to then be transferred to SPSS (Statistical Package of Social Sciences), to be analyzed. Neurophysiological data (peak amplitude and mean amplitude for each condition) were organized and processed using Matlab, and then transferred to SPSS. The findings of these analyses are presented in Chapter VIl.

Chapter VI

RESULTS

In this chapter, the results obtained from the data analysis procedures are described. I report behavioral and neurophysiological results for the one-back and reading verification tasks separately. Synthesis and analysis of these findings is provided in Chapter VII (Discussion).

6.1 One-back Paradigm

6.1.1 Behavioral Results

Figure 9 contains the graphical representation of behavioral data (accuracy and reaction time). Means and degrees of freedom are presented in Table 1. The full ANOVA table for both accuracy and reaction time is given in Appendix K.

A two-way mixed ANOVA with two groups (study vs. comparison) and two levels of stimuli (words and symbols) was conducted on accuracy scores. There was a significant group by stimuli interaction ($F(1,14) = 6.466$, $p = 0.023$, $\omega^2=0.316$[1]). Planned comparisons (paired samples t-tests) indicate that both groups performed significantly better in detecting word

[1] ω^2 was chosen for effect size calculation. Values of around 0.2 represent a small effect; 0.5 represents a medium effect; and 0.8, a large effect (Cohen, 1988).

repetitions than symbol repetitions (t (7) = 4.922, p = 0.002 for the comparison group; t (7) = 2.808, p = 0.026 for the study group). However, independent samples t-tests showed that the comparison group outperformed the study group in detecting repetitions of both words (t (14) = 4.769, p < 0.001) and symbols (t (14) = 2.738, p = 0.016).

A two-way mixed ANOVA on reaction time scores with two groups (study vs. comparison) and two levels of stimuli (words and symbols) revealed significant main effects for group (F (1,14) = 14.929, p = 0.002, ω^2= 0.516) and stimuli (F (1,14) = 9.346, p = 0.009, ω^2= 0.40). Planned comparisons (independent sample t-tests) indicated that the comparison group presented shorter reaction times than the study group in both detecting word repetitions (t (14) = -4.238, p < 0.001) and symbol repetitions (t (14) = -2.644, p = 0.019). Dependent sample t-tests showed that the comparison group showed shorter reaction times for detecting repetition in words than symbols (t (7) = -3. 306, p = 0.013), but the study group did not make this distinction (t (7) = -1.031, p = 0.337).

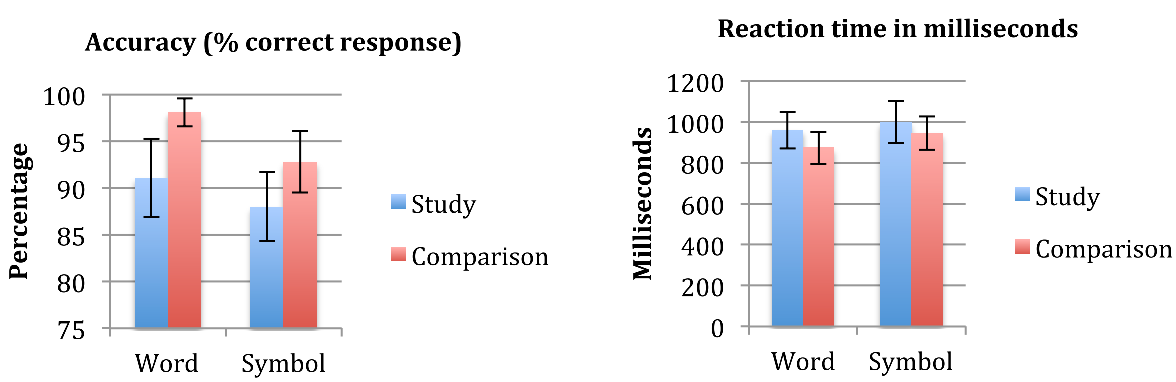


Figure 9. Behavioral results - One-back paradigm

Table 1. Behavioral Results - One-Back Paradigm

	Word - Accuracy	Symbol - Accuracy	Word - RT	Symbol - RT
Groups	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Study	91.1(4.2)	88(3.7)	961(90)	1000(103)
Comparison	98.1(1.5)	92.8(3.3)	875(79)	947(82)

6.1.2 Neurophysiological Results – One back paradigm

Peak amplitude scores were subjected to a three-way mixed ANOVA, with two groups (study vs. comparison), two levels of region (left occipito-temporal vs. right occipito-temporal), and two levels of stimuli (words vs. symbols). Means and standard deviations for peak amplitude scores are presented in Table 2, and the waveforms showing peak amplitudes by region are provided in figure 10 below. Appendix L shows the full ANOVA table and all planned comparisons for the One-back neurophysiological results.

There was an interaction effect of region vs. stimuli ($F(1,14) = 4.663$, $p = 0.049$, $\omega^2=0.25$). Planned comparisons (dependent sample t-tests) show that, as expected, larger N170 amplitude was associated with the comparison group's detection of word repetitions than symbol repetitions, over the left occipito-temporal region ($t(7) = 2.765$, $p = 0.028$); this word/symbol distinction was not significant over the right occipito-temporal region ($t(7) = -0.512$, $p = 0.624$). On the other hand, the study group did not show statistically significant differences in N170 peak amplitude for detecting words vs. symbols repetition over either left ($t(7) = -0.971$, $p = 0.364$) or right ($t(7) = -0.863$, $p = 0.1417$) occipito-temporal regions.

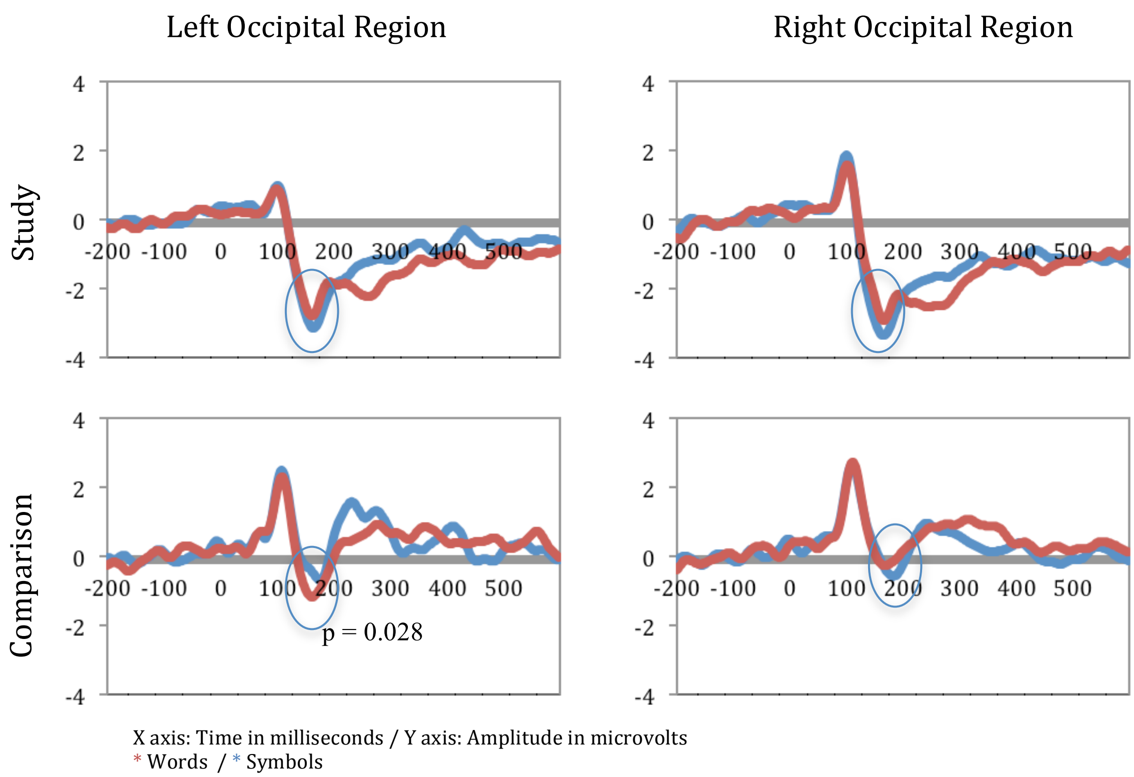


Figure 10: Neurophysiological Results - One-back Paradigm

Table 2. Neurophysiological Results - One-back Paradigm

	Study group		Comparison group	
	Symbols	Words	Symbols	Words
Region	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Left	-3.45 (2.31)	-3.19 (2.66)	-2.14 (1.48)	-2.67 (1.45)
Right	-3.83 (1.94)	-3.54 (2.28)	-1.52 (1.04)	-1.39 (0.97)

6.1.3 Summary – One back paradigm results

1. The study group showed no significant differences in N170 peak amplitude for words vs. symbols over right or left occipito-temporal sensors for the study group.
2. N170 amplitude was significantly larger in response to words than symbols over left occipito-temporal sensors (but not the right occipito-temporal sensors) for the comparison group.

These findings support the hypothesis that the study group would not show a left lateralized N170 effect, and may indicate lack of reading automaticity in adults who are neoliterate. Brain responses from the comparison group were as expected. This is discussed further in Chapter VII.

6.2 Reading Verification Task

6.2.1 Behavioral Results

See figure 11 for a graphical representation.

A two-way mixed ANOVA with two groups (study vs. comparison) and two levels of stimuli (words that matched vs. words that did not match) was conducted on accuracy scores. Means and degrees of freedom are shown in Table 3. The full ANOVA table and planned comparisons are in Appendix M. No statistically significant differences were found in this analysis, indicating that there is no evidence that the groups performed differently when asked to determine whether a visual and auditory word matched or did not match.

A two-way mixed ANOVA with two groups (study vs. comparison) and two levels of stimuli (words that matched vs. words that did not match) was conducted on reaction time scores. Means and degrees of freedom of reaction time scores are shown in Table 3. There was a significant main effect for group (F (1,14) = 50.748, $p < 0.001$, ω^2=0.78) and for stimuli (F (1,14) = 6.665, p = 0.022, ω^2=0.32). Planned comparisons indicate that the comparison group's reaction times to words that matched were significantly shorter than reaction times for words that did not match (t (7) = -3.228, p = 0.014). This was not the case for the study group, in which both words that matched and words that did not match had similar reaction times (t (7) = -1.718, p = 0.13). In addition, reaction times for the comparison group were significantly shorter for both words that matched (t (14) = -7.207, $p < 0.001$) and words that did not match (t (14) = -6.438, $p < 0.001$).

Figure 11: Behavioral results – Reading Verification Task

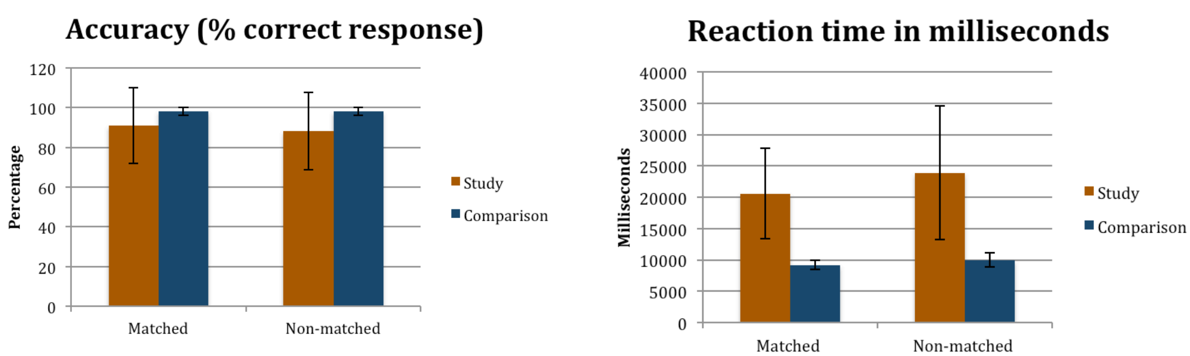


Table 3. Behavioral results - Reading Verification Task

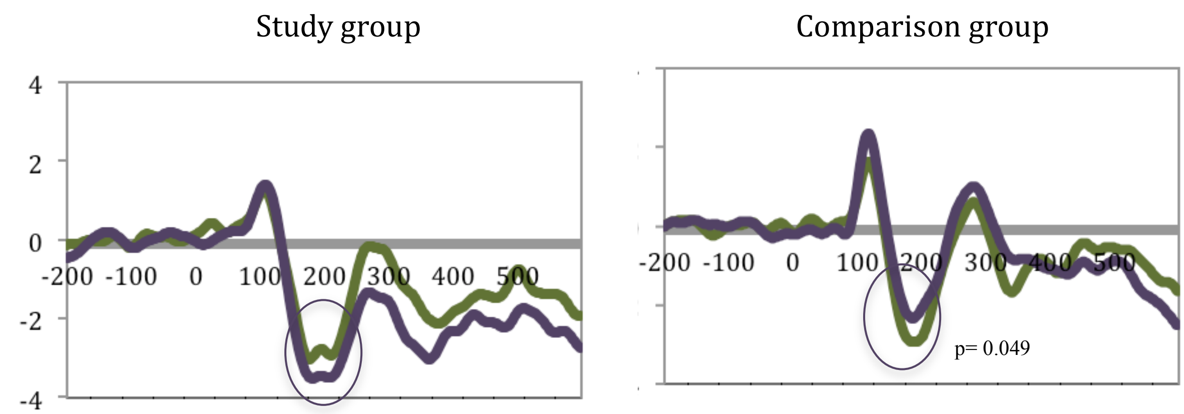
	Matched - Accuracy	Non-matched - Accuracy	Matched - RT	Non-matched - RT
Groups	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Study	90.9(19)	88.2(19.4)	20597(7254)	23887(10636)
Comparison	98.3(2)	98.1(2)	9189(724)	9953(1140)

6.2.2 Neurophysiological Results

See figure 12 for a graphical representation of the neurophysiological results. Appendix N contains the ANOVA table and all planned comparisons.

The neurophysiological analysis of the Reading Verification task was conducted on brain activity related to visual word presentation, and not the matching (or not matching) auditory word pair. This is because for the present study, the purpose of this task is to force participants to conduct conscious grapheme-phoneme conversion, and analyze the N170 associated with it, and not the ability to detect violations. The N170 component happens before the auditory word is presented.

A two-way mixed ANOVA was conducted on peak amplitude scores on data obtained from visual words, with two groups (study vs. comparison) and two regions (left occipito-temporal vs. right occipito-temporal). Table 4 shows the means and standard deviations for peak amplitude scores. There was a significant group by region interaction ($F(1,14) = 8.374$, $p = 0.012$, $\omega^2=0.37$). Planned comparisons (dependent sample t-tests) show that the comparison group had larger peak amplitude for visual words in the left occipito-temporal region compared to the right occipito-temporal region ($t(7) = -2.381$, $p = 0.049$). This left/right difference did not occur in the study group ($t(7) = 1.675$, $p = 0.138$).



X axis: Time in milliseconds / Y axis: Amplitude in microvolts* Left/ * Right

Figure 12: Neurophysiological Results - Reading Verification Task

Table 4: Neurophysiological Results - Reading Verification Task

	Study	Comparison
Region	Mean (SD)	Mean (SD)
Left occipito-temporal	-3.36 (2.15)	-4.29 (1.43)
Right occipito-temporal	-4.03 (2.08)	-3.2 (1.44)

6.2.3 Summary – Reading Verification Task

1. The study group showed no significant differences in N170 peak amplitude for visual words (regardless of whether they matched or not with their auditory pair) over left vs. right occipito-temporal regions.
2. The comparison group showed a significantly greater N170 amplitude over left than right occipito-temporal sensors in response to visual words (regardless of whether they matched or not with their auditory pair).

These findings do not support the hypothesis that both group would show greater amplitude of N170 on the left occipito-temporal region compared to the right occipito-temporal region. This was the case of the comparison group only, but not the study group. This is discussed further in Chapter VII.

6.3 Post-Hoc Analyses

Even though the present study was designed to investigate the N170 component, and therefore analyses focused on brain activity around 200 milliseconds after receiving a visual stimulus in the occipito-temporal region, it was important to explore activation in later time windows and in the other regions in the brain in order to investigate whether other variables are at play that could help to account for the observed behavioral and neurophysiological effects.

Two late time windows were created by obtaining mean amplitude (a) from 200-400 milliseconds, and (b) from 400-600 milliseconds. Six montages were created by obtaining the mean amplitudes recorded from the following groups of electrodes: right-frontal, left-frontal, right-middle, left-middle, right-occipital, and left-occipital.

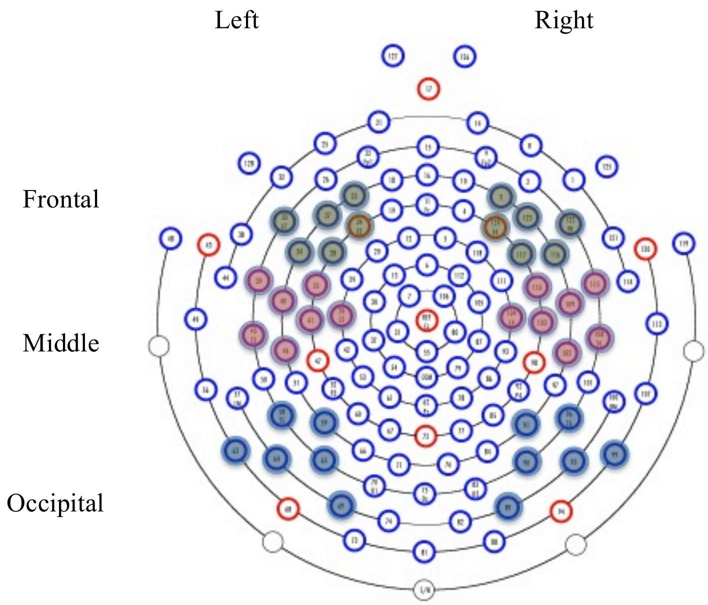


Figure 13: Post Hoc Analysis Montage

6.3.1 One-Back Paradigm

Paired samples t-tests contrasting mean amplitude for words vs. symbols were conducted for each group, each time window, and each montage (left vs. right hemisphere, frontal, central, and occipital regions). No significant results were found over any montage, in either of the groups, for either of the late time windows (200-400 milliseconds and 400-600 milliseconds). The waveforms examined are shown in figures 14 and 15 below.

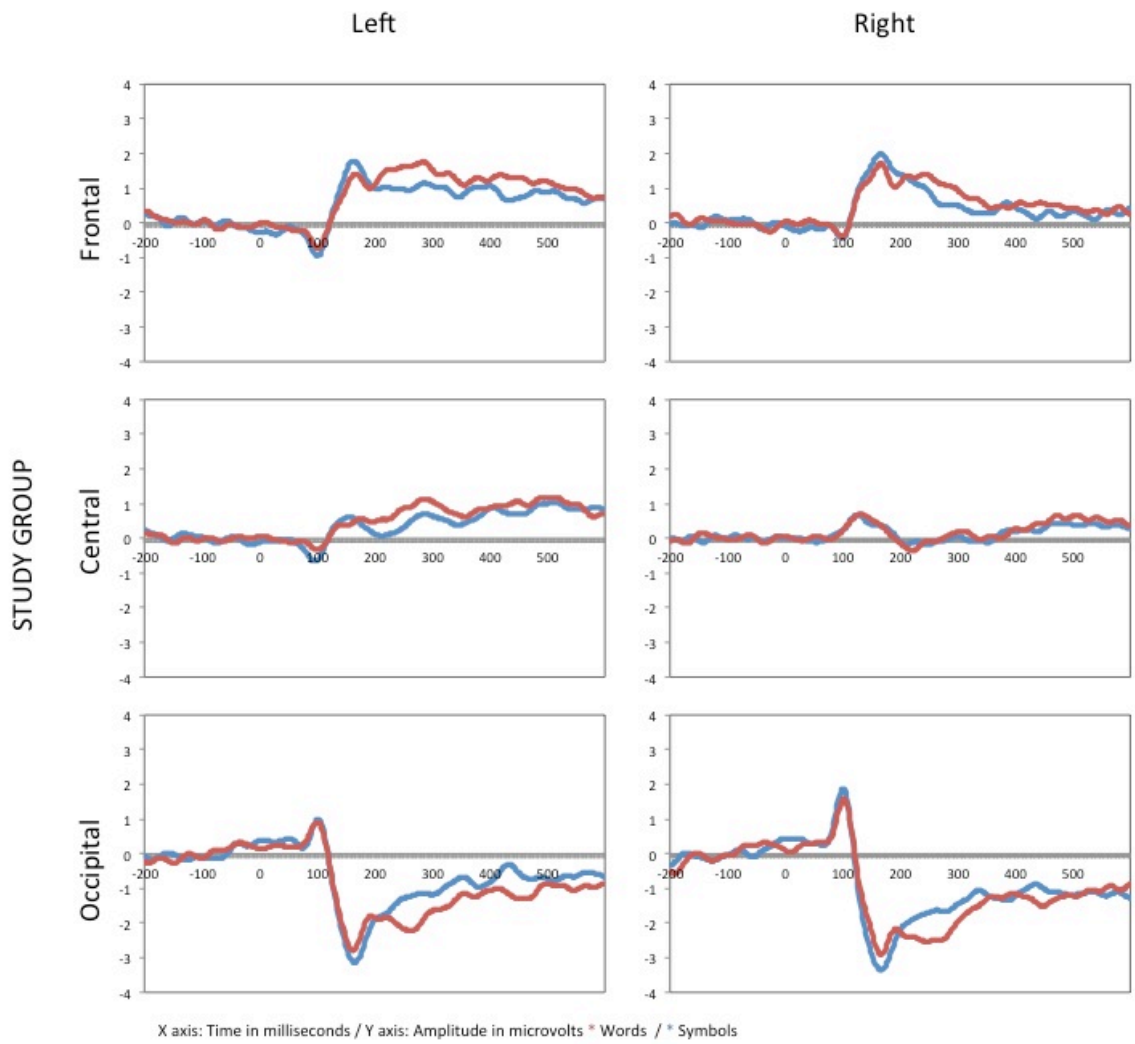


Figure 14: Post Hoc Results – One back paradigm – Study group

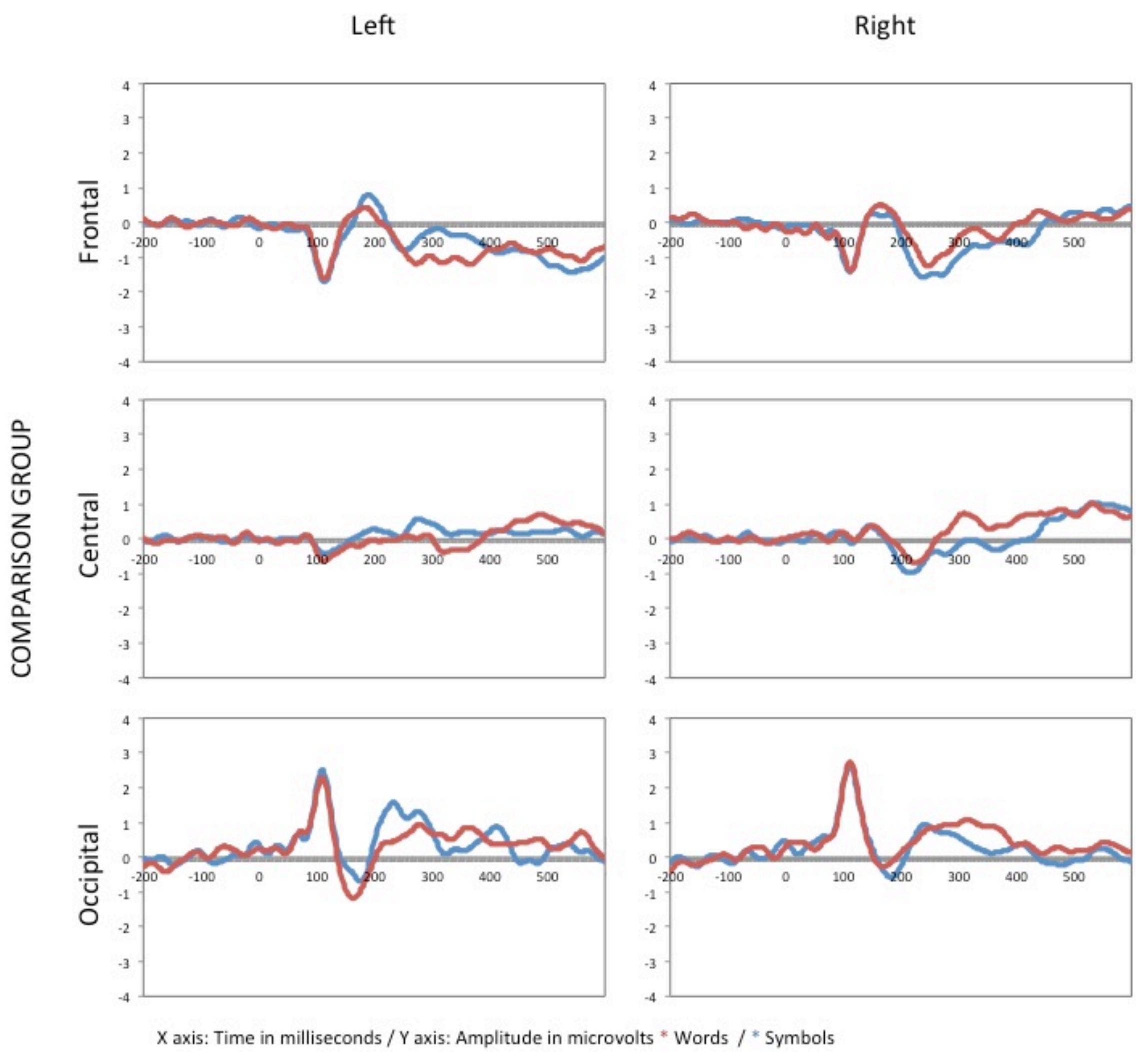


Figure 15: Post Hoc Results – One-back paradigm - Comparison group

6.3.2 Reading Verification Task

Paired samples t-tests contrasting mean amplitudes in response visual words in the left vs. right hemisphere on the three regions (occipital, frontal, and central), on two late time windos (200-400 milliseconds and 400-600 milliseconds) were conducted.

The comparison group showed no significant differences in mean amplitudes in the late time windows over any region, in response to any of the task conditions. However, the study group showed a significantly greater mean amplitude in the ERP responses to visual words over the left central region, compared to the right central region, in both late time windows (200-400 milliseconds: $t(7) = 9.109$, $p < 0.001$; 400-600 milliseconds: $t(7) = 7.317$, $p < 0.001$). Likewise, mean amplitude for visual words was significantly larger for this group over left frontal sensors than right frontal sensors, for both late time windows (200-400 milliseconds: $t(7) = 4.725$, $p = 0.002$; 400-600 milliseconds: $t(7) = 10.709$, $p < 0.001$). Table 5 displays means and standard deviations, and figure 16 shows the waveforms that were evaluated.

		Study group		Comparison group	
		Mean	SD	Mean	SD
Left Occipital	200-400 ms	-1.22	1.03	-0.73	0.91
Left Occipital	400-600 ms	-1.35	1.60	-0.96	1.56
Right Occipital	200-400 ms	-2.16	1.49	-0.32	1.16
Right Occipital	400-600 ms	-2.10	1.96	-1.38	1.17
Left Central	200-400 ms	1.26	0.65	-0.50	0.81
Left Central	400-600 ms	1.45	1.15	-0.61	0.70
Right Central	200-400 ms	-0.70	0.64	-0.19	1.01
Right Central	400-600 ms	-0.78	0.71	-0.90	1.45
Left Frontal	200-400 ms	2.54	1.30	0.80	1.57
Left Frontal	400-600 ms	2.79	1.66	1.13	1.91
Right Frontal	200-400 ms	0.11	1.14	0.70	1.15
Right Frontal	400-600 ms	-0.63	1.75	1.14	1.54

Table 5: Reading Verification task – Post Hoc results

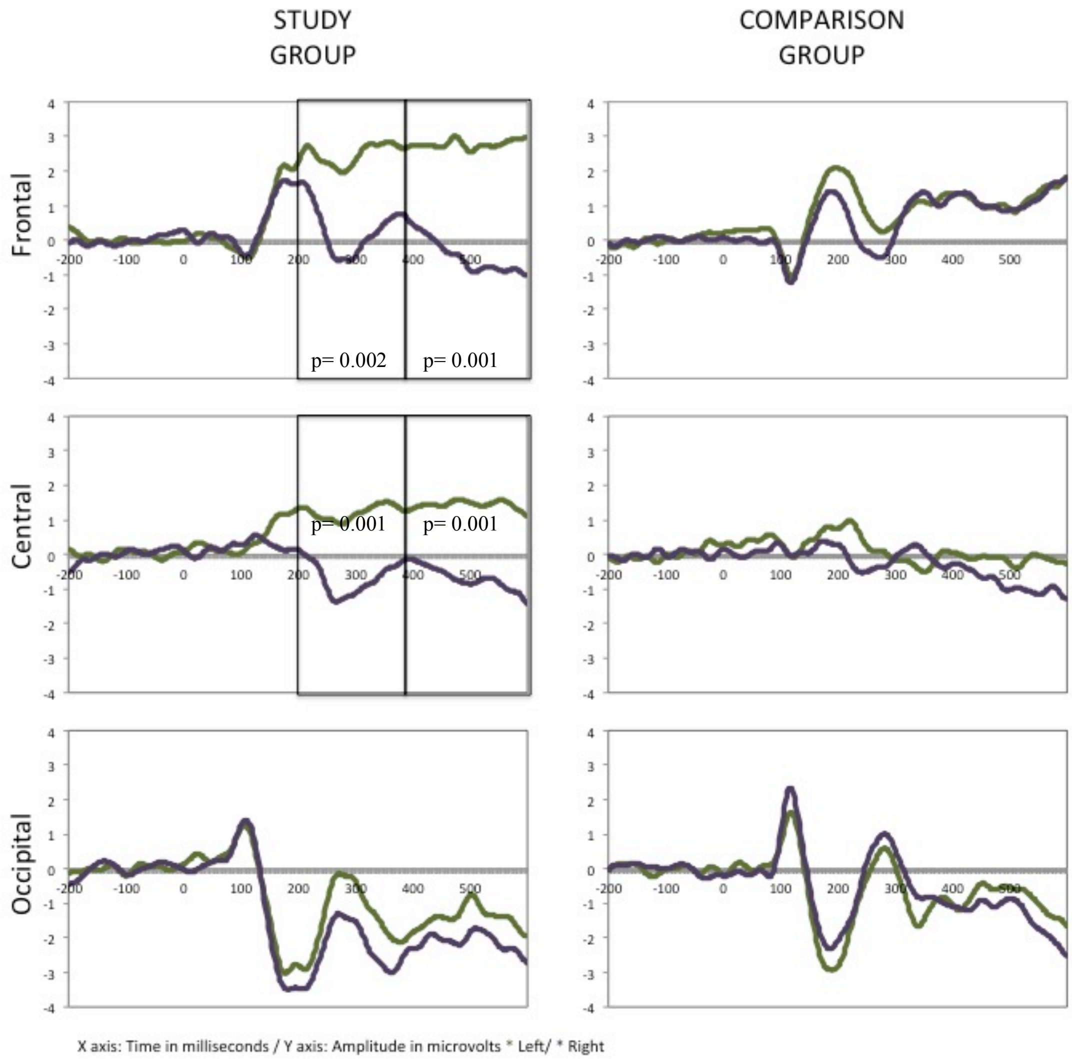


Figure 16: Post hoc results - Reading Verification Task

6.3.3 Summary – Post hoc results

1. On the reading verification task, the study group showed significant mean amplitude differences in response to visual words (regardless of whether they matched or not with their auditory word pair) over the left hemisphere vs. the right hemisphere, for central and frontal region, from 200-400 milliseconds, and from 400-600 milliseconds. No such distinction was seen in the comparison group.

This post-hoc finding suggests that the study group presented greater left hemisphere activity for visual words in regions and time windows outside the scope of the N170 component. Timing differences and activation of other areas could indicate the recruitment of a more extensive network to perform reading tasks. This will be further discussed in Chapter VII.

Chapter VII

DISCUSSION

The aim of this study was to explore visual word specialization in adults who are neoliterate. Behavioral studies have shown that when acquired in adulthood reading is not automatic, reflected by slow and effortful reading. Although many brain imaging studies have looked at localization of reading-related brain activation in literates, illiterates and neoliterates, there is a gap in the literature in terms of the temporal resolution of the activation of these areas. EEG is one imaging methodology that has the requisite millisecond level timing resolution to effectively evaluate brain activations associated with fast sensory and cognitive processes like those involved in reading.

The current study explored electrophysiological activity from the visual word form area in reading tasks in neoliterate and literate adults, to examine the neural correlates of reading automaticity.

Study hypotheses of the study were derived from the "phonological mapping hypothesis," which asserts that the left lateralization of the ERP component N170 in response to a visual word is an indication of reading expertise, and it is the consequence of constant conversions between graphemes and phonemes that occur during learning to read, especially in languages with transparent orthographies (Maurer & McCandliss 2007). Since the N170 component can be modulated by attentional focus (Yoncheva et al., 2010), the present study explored word recognition in two conditions that varied the degree of attention to linguistic components of reading: (1) a one-back paradigm to elicit automatic word recognition (with attentional focus on visual word form instead of grapheme-phoneme conversion), and (2) a reading verification task to elicit intentional word recognition (with attentional focus on grapheme-phoneme conversion). The focus on automatic and intentional word recognition comes from previous behavioral studies showing that, when literacy is acquired in adulthood, people are able to learn the grapheme-phoneme conversion rules of reading, but their reading tends to be slow and effortful, indicating a possible lack of automaticity of the skill (Abadzi, 2003). If, in fact, automaticity were an issue, we wanted to see if shifting participants' attention to the actual grapheme-phoneme conversion component of reading would yield a left lateralization of the N170. Outcomes from the group of adults who are neoliterate were compared to those of a group of adults who learned to read in childhood to answer two research questions.

Results will be interpreted according to each question.

7.1 Research Question 1

Do adults who are neoliterate (study group) show evidence of ***automatic*** *word recognition indexed by eliciting reading-related brain activity in tasks that do not necessarily require reading, as seen in adults who are expert readers (comparison group)?*

In the one-back paradigm, the comparison group showed a left lateralized N170 effect for words. That is, words elicited larger N170 amplitudes than symbols over the left occipito-temporal region. This effect did not occur in the study group, who showed responses of similar amplitudes to both words and symbols.

Larger N170 amplitudes for words than for symbols on the left occipito-temporal regions, as seen in the comparison group, is an indication of word-reading expertise (Maurer & McCandliss, 2007). This effect could be explained on three levels: (1) general visual expertise; (2) the linguistic weight of words; and (3) the implicit-reading nature of the task. On the general visual expertise level, it is assumed that common visual stimuli elicit larger N170 amplitudes than uncommon visual stimuli (Tanaka & Curran, 2001). Expert readers have had more exposure to visual words than to laboratory-made symbols; therefore, larger N170 amplitudes are expected for words than symbols. The same is true, however, for the study group, who have certainly been exposed to words much more than symbols, during their literacy training and before that, since they also live in a society where the symbols of literacy are all around – we are all surrounded by the written word all the time, whether or not we have the skills to access it. Nevertheless, it seems that reading exposure was not sufficient for tuning to automaticity in the reading systems of the study group participants' brains, since the word / symbol recognition task did not elicit larger amplitudes for words than symbols in either left or right occipito-temporal regions.

The linguistic level refers to the fact that words, in addition to being visual stimuli, carry linguistic information. Since, for most people, the left hemisphere is the dominant hemisphere for language, expert readers tend to show this expertise effect (words larger than symbols) over the left occipito-temporal region (Maurer & McCandliss, 2007). Participants from the study group did not show the effect over the left hemisphere, indicating that processing of words and symbols was probably not recruiting systems known to be specifically targeted by linguistic stimuli in the brains of literate adults.

In terms of the implicit-reading nature of this task, when participants were asked to detect immediate repetitions of words or symbols, they were not being instructed to read. In fact, reading was not necessary to perform this task. Therefore, reading automaticity is assumed when the expertise effect (words larger than symbols on the left occipito-temporal region) occurs, even when there is no actual reading requirement built into the task. The results from the one-back paradigm provide evidence of a lack of reading expertise (automaticity) among the participants from the study group investigated here.

These findings support the behavioral research to date, that has indicated the difficulty in attaining reading automaticity when literacy is acquired in adulthood (Villa-Carpio Fernández et al., 2002; Royer et al., 2004). This could be one important factor that contributes to the susceptibility of neoliterate adults to "relapse" back into illiteracy (Niwaz et al., 2010). Behavioral data obtained from this neurophysiological experiment support the possible lack of automaticity, since participants from the comparison group were more accurate and faster in their responses across tasks than participants from the study group. Also, study group participants showed a discrepancy between fluent and effortful word recognition scores on the word recognition behavioral test. This means that, when allowed to read slowly and to decode each word, participants obtained better scores than when they were required to read fast, with scoring that took account of only words that were recognized easily and immediately. The comparison group did not perform better on the reading tasks when allowed additional time, again showing that automaticity in reading is available to the comparison group but not to the study group.

It has been proposed that the constant use of grapheme-phoneme conversion during learning to read contributes to the specialization of the visual word form area in the left hemisphere (Maurer & McCandliss, 2007). Grapheme-phoneme conversion heavily depends on phonological awareness, the ability to manipulate sounds of language. This study and many others have pointed out that neoliterates seem to struggle with phonological awareness and that, although they know the reading rules, the grapheme-phoneme conversion process is inefficient and non-automatic (Greenberg et al., 1997, 2002; Villa Carpio Fernández et al., 2002). Therefore, inefficient grapheme-phoneme conversion associated with poor phonological awareness could be preventing, slowing, or altering left occipito-temporal specialization in neoliterate adults.

In response to Research Question 1, then, the current study reveals evidence of a lack of automatic word recognition in neoliterate adults, either at the level of the brain or in behavioral measures, in a task that does not specifically require reading.

7.2 Research Question 2

> *Do adults who are neoliterate (study group) show evidence of* ***intentional*** *word recognition indexed by eliciting reading-related brain activity in tasks that require reading, as seen in adults who are expert readers (comparison group)?*

The purpose of the reading verification task was to shift attention to grapheme-phoneme conversion on the conscious level, forcing participants to decode each word, thereby placing an emphasis on the linguistic component of visual word processing. The task consists of asking participants whether a visual word matches or does not match an auditory word. This task assumes high accuracy rates in both groups, but since automatic visual processes occur way before behavioral response, accurate and inaccurate behavioral responses were included in the neurophysiological data. It is important to note that both group showed high scores (above 88% correct responses); therefore inaccurate responses do not present a risk to bias the data.

Based on the premise that participants from the study group already knew the rules of reading, as evidenced by their high-enough effortful word recognition scores, it was hypothesized that on an intentional word recognition task, they would perform similarly to the participants from the comparison group.

This hypothesis was based on work by Yoncheva et al. (2012), in which people who recently learned an artificial script by learning grapheme-phoneme correspondence showed a left lateralized N170 effect for words on a reading verification task after initial training. Yoncheva et al.'s participants did not show left hemisphere lateralization for words on a one-back paradigm, however. Together these findings suggest that bringing "reading" of the new script to a more conscious level permitted the use of emergent visual word specialization.

In the current study, contrary to what was expected, participants from the study group did not show a left lateralized N170 in the word verification task, although the expected N170 was evidenced in the comparison group. This suggests that, for this particular group of neoliterate individuals, even in a task that renders reading mandatory, there is no evidence of left-hemisphere specialization for visual words. In fact, there was a non-significant subtle tendency towards a larger N170 amplitude over the *right*, rather than left, occipito-temporal region for the study group. This should be explored in further studies, since the participants from Yoncheva et al. (2012) who were trained by using whole word recognition (and not grapheme-phoneme conversion) showed a right-lateralized N170 for words in a reading verification task. The use of a whole-word/orthographic strategy to read words in adults who are acquiring literacy is commonly seen in behavioral studies (Greenberg et al., 1997, 2002; Villa Carpio Fernandez et al., 2002), and these attribute the use of this strategy to poor phonological processing. It is common to see right-lateralized N170 effects in children who are in the process of acquiring literacy skills very early on (Maurer, Brandeis, & McCandliss, 2005). This effect is defined as a familiarization effect, and it is supposed to reflect recognition of visual objects that are commonly encountered in the environment – which is true of written words for most people. However, as mentioned above, this familiarity effect was not observed as a factor in the N170 lateralization effects observed for the current study group. It remains to be seen, and experimentally investigated, whether whole-word recognition strategies in adults directly affect the organization and lateralization of the N170, though it could be predicted that whole word reading would not support the specialization of the VWFA that relies on repetitive and long-term experience of grapheme-phoneme conversion.

Accuracy scores from the reading verification task revealed no significant differences between the groups with respect to matched word pairs. This confirms that the participants from the study group were able to recognize the words, which was an important inclusion criterion. The significantly lower accuracy in response to mismatched word pairs for the study group on this task could be accounted for, in part, by the nature of the task. Requiring distinct responses to the matched and mismatched words (press button 1 if the words match, button 2 if they do not) adds to the processing load of a task when compared to some other task variants (e.g., a go/no go task, where a response is required only to one condition), and it may be that a go/no go version of the word verification task would have supported the limited processing resources available to the neoliterate participants to a point where accurate "reject" decisions could have been made in the mismatch condition (see Perea, Rosa & Gómez, 2002, for discussion of the advantages and disadvantages of go/no go variants of lexical decision tasks). Reaction time data also show significant differences between the groups, with the study group responding more slowly than the comparison group both in response to matched and mismatched word pairs. This supports the data from the one-back paradigm that indicate a lack of reading automaticity in the study group.

Even though no left occipito-temporal lateralization for word reading was found in the N170 time window for the study group, post-hoc investigations of data from the word verification task did reveal a significant left-lateralized response to matched words in later time windows (from 200-400 milliseconds, and from 400-600 milliseconds), over frontal and central regions. Dehaene et al. (2010) assert that people who acquire literacy in adulthood need to recruit additional cognitive resources to compensate for the lack of specialization. This recruitment is associated with serial, effortful reading, and is reflected in a more widely-distributed set of functional activations than seen in literate adults. The presence of the late left-lateralized responses in frontal and middle regions of the brain from the study group could, therefore, indicate recruitment of a broader network of brain regions for the conscious recognition of words, in part as a compensation for the demonstrated lack of reading automaticity.

7.3 Study limitations

One of the major limitations of the current study is heterogeneity of the sample. There are multiple reasons for not having access to reading instruction in childhood. According to Castro-Caldas (2004), illiteracy could be the result of social problems in which resources were not available, lack of practice after successful literacy acquisition in childhood, or reading disabilities. To overcome this limitation, the present study delimited the study population by only including participants who did not attend school in childhood for social reasons. The background questionnaire specifically asked about these issues, and the reasons given by each participant are shown in Appendix I.

Another limitation of this study involves the selected terminology for describing the various levels of literacy associated with study participants. Terminology used to describe populations of readers at differing levels of experience and exposure is widely variable. For example, in the United States, people who reach adult literacy instruction are considered low-literates, and adults with reading levels from 2nd to 7th grade are included. Most of the reading theories are based on this population, which is different from the population studied here. Therefore, for the purposes of the present study, I elected to use the term "neo-literate" to differentiate this sample from the broader "low-literate" group. The purpose of this study was to investigate if adults who recently learned to read during adulthood reach reading automaticity, which means that, a more appropriate term is "neoliterate" (new reader).

The third limitation has to do with the language selected for this study. Spanish was chosen because of its transparent orthography. More consistent grapheme-phoneme conversion practices during learning to read generate clearer left N170 lateralization (Maurer & McCandliss, 2007). Therefore, we wanted to select a language that has maximally transparent grapheme-phoneme correspondences, so as to maximize the possibility that we would be able to observe lateralization effects in the study population, and minimize the possibility that observed effects could be attenuated by properties of the language of the study. Nevertheless, even though Spanish provides an ideal medium for a study where orthographic transparency is important, the participants from this study all live in or near English-speaking communities, and have done so for many years. Even though they are not fully proficient in English, some exposure to that language is unavoidable. We also cannot say that the adult neoliterates in this study have never had exposure to written language prior to joining literacy instruction in adulthood. Written language is everywhere around us, and there has certainly been exposure throughout their lives and their social and cultural engagements. Even so, we were able to demonstrate that this kind of exposure was not sufficient, in the case of the study group, to enable automatic reading or an “expert-like” response to written words.

The tasks used in the study only approximate reading tasks that are like the literacy requirements of real life. Most such limitations are unavoidable, imposed by the constraints of the brain imaging technology and the need for very precise control and manipulation of the timing and sequencing of stimulus presentation. Nevertheless, it is possible that, in more realistic situations and environments, the study participants may respond differently to orthographic stimuli, and that their reading strategies may be adequate to support necessary literacy-based practices in daily living. In some cases it is possible that additional task demands (like pressing a response button for both valencies of a binary decision) might have had an impact on performance, and other task structures should be considered for future investigations.

Lastly, although Spanish literacy instruction is usually based on phonics, we had no control over how participants were taught or the amount of time they dedicated to reading and practicing on their own. Due to these limitations, generalizability of study findings is necessarily limited in scope.

7.4 Recommendations for further studies

The sample obtained for this study comes from immigrants who did not acquire literacy in their first language, and were provided with the opportunity to learn to read in their native language. Although they are not proficient, the fact that they have been exposed to a second language is a limitation. It would be beneficial to replicate this study in a truly monolingual population to confirm that the differences in the groups were not related to the second language exposure.

In terms of the Reading Verification Task, it would be valuable to analyze the effects of semantic violations by evaluating the ERP component N400 (Luck, 2005). This component is associated with the detection of semantic violations, that is, words that do not match in their visual and auditory presentation from the reading verification task, would elicit larger N400 than words that match. This approach to analysis could potentially confirm the findings from the behavioral data (accuracy).

The evaluation of automaticity by targeting the Visual Word Form Area is associated with both temporal resolution and spatial resolution. The current study assessed the temporal level by using EEG techniques that allow obtaining information with millisecond precision given that it takes around 250 milliseconds to process a word. However, it is also true that spatial resolution plays an important role when the brain recognizes print stimuli as language. The Visual Word Form Area has been localized in the left occipito-temporal region, left fusiform gyrus when assessing expert readers (Cohen & Dehaene, 2004; Cohen et al. 2000, 2002; Dehaene et al., 2002, 2010; McCandliss, Cohen & Dehaene, 2003; Schlaggar & McCandliss, 2007; Vinckier et al., 2007). The VWFA gets fine-tuned to print stimuli by the combination of training in reading, and the maturation of visual and auditory areas of the brain (Schlaggar & McCandliss, 2007). Dehaene et al. (2010) found that tuning of the VWFA to print stimuli also occurs when reading is acquired in adulthood, when the visual and auditory areas of the brain have already been established. However, as opposed to children, adults who are learning to read show activation in other areas of the brain, in addition to the activation of the VWFA seen in children (bilateral mesial fusiform area, right posterior parietal cortex) during reading tasks. The recruitment of broader networks was also found in the current study, but these results should be interpreted with caution, given the spatial constraints of electrophysiological methods. Single word reading tasks, such as the ones applied on this study, have yet to be used to target automatic processing when learning to read in adulthood by looking at the spatial dimension. Therefore it is important to use methodologies with high spatial resolution, such as fMRI, in combination with brain imaging modalities that provide good temporal resolution. The information provided from the combination of EEG and fMRI could expand the current knowledge on the acquisition of reading automaticity in adulthood.

It is important to highlight that this study is the first using a one-back paradigm and a reading verification task to assess reading automaticity in adults who recently learned to read. A simple design was necessary to verify the usefulness of the tasks. This current study asked whether adults who are neoliterate could differentiate automatically (within 170 milliseconds) linguistic from non-linguistic stimuli on a single word reading task. However, other experimental manipulations should be considered to better understand word reading automaticity (or lack of automaticity) in adults who are neoliterate. For example, it would be of interest to investigate the neural correlates of categorical distinctions within the linguistic domain, that is, the identification of words vs. pseudowords. Expert readers from languages of transparent orthographies show similar activation for words and pseudowords (both left lateralized), while expert readers from languages with opaque orthographies show more left lateralization for words than pseudowords (Maurer et al., 2005a, 2005b). It is hypothesized that, since opaque orthographies do not have clear grapheme-phoneme conversion rules – which means that irregular words are common – participants encounter ambiguity when presented with a pseudoword. This could lead to a reduction in the level of dependence on phonological aspects of language compared to the decoding of a high frequency word (Maurer et al., 2005a and b). Behavioral studies (Greenberg et al., 1997, 2002; Villa Carpio Fernandez et al., 2002) have shown that adults who are neoliterate have difficulties with rapid grapheme-phoneme conversion, and this pushes them to a greater reliance on orthographic strategies for word reading. This strategy is commonly used when words are already known, or when reading irregular words (usually in opaque orthography). Since participants from the current study were Spanish speakers (transparent orthography) who were learning to read their first language, pseudowords and words should evoke the same neural responses; however, since they seemed to use orthographic strategies rather than phonological strategies to read words, it would be interesting to evaluate similarities (or dissimilarities) between activations associated with decoding pseudowords (that in Spanish would require phonological strategies) versus high frequency words (that might not require phonological strategies).

To overcome the limitation of not knowing participants' abilities and brain responses to the stimuli prior to the literacy training it is recommended to conduct a longitudinal study in order to evaluate the participants before, during and after training. Such a study would provide a timeline of changes that happen in the brain while literacy is being acquired, and that could be contrasted to behavioral data obtained during the process, to assess not only if, but how automaticity is acquired in adulthood. A similar design has been used in a study focusing on neural tuning for print in children, in which participants were evaluated with the one-back paradigm before and after reading (Maurer et al., 2006). The study provided evidence of the timeline in which left lateralization occurs when learning to read during childhood. Since the adult brain that learns to read tends to use broader networks, the timeline in which the specialization occurs, and which areas of the brain get activated, becomes crucial.

7.4 Conclusions

The objective of the current study was to investigate the neurophysiological correlates of word recognition in adults who are neoliterate in order to examine the question of whether the brains of people who learn to read in adulthood show evidence of word recognition automaticity. Outcomes of the study suggest that, right after the initial literacy training, adults who are neoliterates do not show evidence of word reading automaticity, as evidenced by the lack of a left lateralized N170 on implicit and explicit reading tasks. Post-hoc analyses from the present study showed larger left hemisphere activation in later time windows in frontal and mid areas of the brain, indicating the possible application of a compensatory strategy by the study group. Interestingly, this only happened in the reading verification task, not in the one-back task. This pattern of responding suggests that study group participants did not even attempt to read during the fast presentation of words in the one-back paradigm, supporting the view that automaticity has not yet been acquired by this group of newly-literate adults.

Studying the neurophysiological responses of adults who are learning to read by using this paradigm has many implications for theories of reading, and for pedagogical approaches used to inform literacy instruction for adults. In terms of contributions to the literature, this study provides support for the Phonological Mapping Hypothesis (Maurer & McCandliss, 2007). The hypothesis posits that grapheme-phoneme conversion during learning to read specializes the visual word form area allowing it to detect linguistic characteristics of visual stimuli, and reading becomes automatic. Since behavioral research report slow and effortful reading performance in adults who are neoliterate, the fact that no left hemisphere specialization was seen in the N170 component, indicates that this component could be considered as an index of reading automaticity.

In terms of educational implications, this study provides insights into the processes that people who are neoliterates apply, consciously and unconsciously, at different stages of reading acquisition. In turn, this information could be used to evaluate the effectiveness and impact of different instructional programs, different amounts of practice, and different pedagogical techniques, and to help us answer questions about the optimal parameters for effective literacy instruction. Current behavioral assessments at the end of literacy programs provide information about people's general reading abilities, but at the moment there is no behavioral test that allows for the detection of automaticity achievement in reading. The identification of reading automaticity indicators using neurophysiological methods will allow for a better assessment of people who reach for adult literacy instruction, adding a unique dimension to conventional testing that includes a behavior-independent measurement. Ultimately it is possible that these insights could contribute to the design and implementation of new instructional paradigms for teaching reading, appropriate to the needs of adult learners.

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APPDENDICES

Appendix A: Background questionnaire

Background questionnaire

N170 visual word specialization on implicit and explicit reading tasks in Spanish speaking adult neoliterates

General information

1. In what country were you born?

2. How old were you when you moved to the United States?

3. How many years have you lived in the United states?

4. How old are you?

Language background

1. When you were growing up, what language or languages were usually spoken in your home?

2. What language or languages did you learn to speak before you started school?

3. What language did you first learn to read and write? (for controls)

4. How old were you when you learned to speak English?

5. Have you taken English as a second language class?

6. Which language do you usually speak now?

7. What other language do you often speak now?

Educational background

1. What is the highest level of public or private education you completed? (for the experimental group read: What is the highest level of public or private education you completed before starting the literacy program?

2. What was the main reason you stopped your public or private schooling when you did?

a. You are currently in school
b. Financial problems
c. Did not do well in school
d. Did not like school or was bored in school
e. Expelled from school of asked to leave
f. Wanted to work
g. Wanted to go into the military
h. Personal illness, disability or pregnancy
i. Family reasons
j. School not available of not accessible
k. Did not feel safe in school
l. Other

3. When did you start the literacy program? (for experimental group only)

4. When did you finish the literacy program? (for experimental group only)

5. Have you been diagnosed with a learning disability?

- This questionnaire has been adapted from the National Assessment of Adult Literacy: English background questionnaire (Kutner, et al., 2007)

Appendix B: Phonological Awareness Tent

Prueba para la Evaluación del Conocimiento Fonológico

ACTIVIDAD 1ª: IDENTIFICACIÓN DE SÍLABAS

INSTRUCCIONES:

"Te voy a enseñar un juego. Mira estos dibujos (señalamos la fila del ejemplo) y dime el nombre de cada uno (si no sabe los nombres se los decimos). Ahora tenemos que señalar el dibujo donde se oiga /ca/".

EJEMPLO:

Comenzamos con el primer dibujo: "Esto es una nube".Pronunciamos muy despacio y marcando las sílabas: "¿Suena /ca/ en la palabra /nube/? No, porque hemos dicho /nube/ y en esa palabra no hay ningún sonido /ca/". Hacemos lo mismo con el resto de los dibujos y ayudamos a darse cuenta que en la palabra /cama/ suena el sonido /ca/.

Una vez seguros de que ha entendido la tarea, se realiza la actividad.

Task 1: Syllable identification

Instructions: "I will show you a game. Look at these pictures (point the row in the example). Tell me their names (if participant does not know the name, the evaluator does). Now please point the picture that has the sound /ca/".

Example:

The evaluator should start with the first picture: "This is a *nube*". The evaluator should pronounce slowly, stressing on each syllable: "Does *nube* have the sound /ca/? No, because we have said /*nube/* and there is no /ca/ sound". We do the same thing with the remaining pictures and the evaluator will help the participant to realize that there is a /ca/ sound in the word /cama/.

Once the evaluator realizes the participant understood the task, he/she can start the assessment.

ACTIVIDAD 2ª: IDENTIFICACIÓN DE FONEMAS

INSTRUCCIONES:

"Este juego es parecido al anterior. Mira estos dibujos (señalamos la fila del ejemplo) y dime el nombre de cada uno (si no sabe los nombres se los decimos). Ahora tenemos que adivinar cual es el dibujo donde se olga /z/ (alargamos el sonido zzzzzzz)".

EJEMPLO:

Comenzamos con el primer dibujo: "Esto es un coche". Pronunciamos muy despacio y marcando los fonemas: "¿Oyes en esta palabra el sonido /z/ (zzzzzz)? No, porque hemos dicho /coche/ y en la palabra /coche/ no hay ningún sonido /z/".Hacemos los mismo con el resto de los dibujos y palabras, ayudándole a identificar el sonido /z/ de la palabra /lazo/ (alargando el sonido /lazzzzzo/).

Una vez seguros de que ha entendido la tarea, se realiza la actividad.

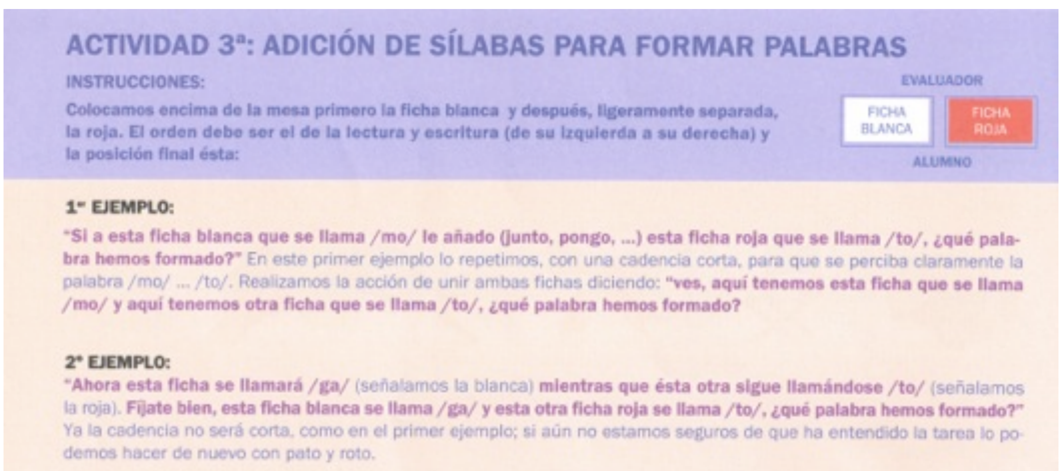
Task 2: Phoneme identification

Instructions: “This game is like the one before. Look at these pictures (point the row in the example) and tell me their names (if participant does not know the name, the researcher will name them). Now your job is to guess which picture has the sound /z/ (the researcher should make the sound longer).

Example

The evaluator should begin with the first picture: “This is a *coche.* The evaluator should pronounce slowly, stressing on each phoneme: “Do you hear the sound /z/ (zzzzzzz) on this word? No, because we have said /*coche*/, and there is no /z/ sound there”. The same should be done with the rest of the pictures, helping them to identify the sound /z/ on the word /*lazo/*.

Once the evaluator realizes the participant understood the task, he/she can start the assessment.



ACTIVIDAD 3ª: ADICIÓN DE SÍLABAS PARA FORMAR PALABRAS

INSTRUCCIONES:

Colocamos encima de la mesa primero la ficha blanca y después, ligeramente separada, la roja. El orden debe ser el de la lectura y escritura (de su izquierda a su derecha) y la posición final ésta:

1ᵉʳ EJEMPLO:

“Si a esta ficha blanca que se llama /mo/ le añado (junto, pongo, ...) esta ficha roja que se llama /to/, ¿qué palabra hemos formado?” En este primer ejemplo lo repetimos, con una cadencia corta, para que se perciba claramente la palabra /mo/ ... /to/. Realizamos la acción de unir ambas fichas diciendo: “ves, aquí tenemos esta ficha que se llama /mo/ y aquí tenemos otra ficha que se llama /to/, ¿qué palabra hemos formado?

2º EJEMPLO:

“Ahora esta ficha se llamará /ga/ (señalamos la blanca) mientras que ésta otra sigue llamándose /to/ (señalamos la roja). Fíjate bien, esta ficha blanca se llama /ga/ y esta otra ficha roja se llama /to/, ¿qué palabra hemos formado?” Ya la cadencia no será corta, como en el primer ejemplo; si aún no estamos seguros de que ha entendido la tarea lo podemos hacer de nuevo con pato y roto.

Task 3: Syllable addition to make words

Instruction: The evaluator will put the white card on the table, then the red card on reading order (from left to right) See diagram.

1st Example:

“If this white card named /*mo*/, I add this red card named /to/, what word have we made?” The evaluator should repeat the first example quickly so it clear that the word is “*moto*”. Then the evaluator should put both cards together saying: “See, here we have a card named /*mo*/, and another one named /*to*/, what is the word?

2nd Example

“Now this chard is named /*ga*/ (the evaluator should select the white card) while this other one is still named /*to*/, what word did we make? Look closely, this white card is named /*ga*/, and this red one is /*to*/, what is the word? The evaluator should not repeat this example quickly, so that the participant can perform the task. The evaluator can try with two more words if the participant does not understand (*pato and roto).*

ACTIVIDAD 4ª: ADICIÓN DE FONEMAS PARA FORMAR PALABRAS

INSTRUCCIONES:

1ᵉʳ EJEMPLO:

“Vamos a realizar un juego parecido al que has hecho antes” Le enseñamos la ficha blanca y le decimos: **“Mira, a esta ficha blanca la vamos a llamar /pi/”** La colocamos detrás de la blanca. **“¿Te has dado cuenta?, primero he puesto la ficha blanca que se llama /pi/ y después he puesto la ficha roja que se llama /o/, ¿qué palabra hemos formado?”** Si no sabe la respuesta se la decimos.

2º EJEMPLO:

“A esta ficha blanca la vamos a llamar /ga/”. La colocamos en la mesa. **“Y a esta ficha roja la llamaremos /s/”.** La colocamos detrás de la ficha blanca.**“Primero he puesto la ficha blanca que se llama /ga/ y después he puesto la ficha roja que se llama /s/ (ssss), ¿qué palabra hemos formado?”** Si ha entendido la actividad se inicia ésta, en caso contrario intentarlo de nuevo con dos, más, los.

Task 4: Phoneme addition to make words

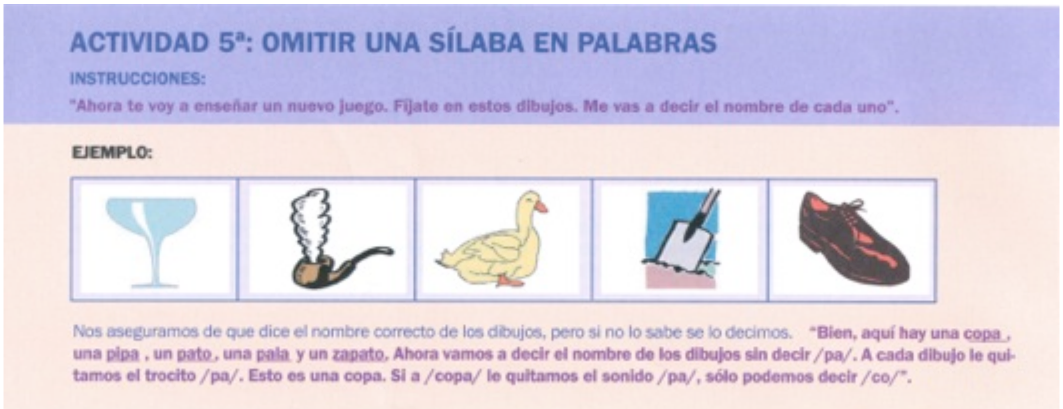
Instructions:

1st example:

“We will play a similar game”. The evaluator should show the white card and say: “Look, this white card. We will call it /*pi*/”. The evaluator will put that one behind the white card. “Did you see? First I put the white card /*pi/*, and after it, I put the red card /*o*/. What word did we make? If the participant does not know the answer, we give it to him/her.

2nd example:

“We will call this white card /*ga*/”. The evaluator should put the card on the table. “And this red card, we will call /*s*/”. The evaluator puts the card behind the white card. “First I put the white card /*ga*/, and then the red /*s*/. What word did we make? If the participant understood, the evaluator should begin the task, otherwise, practice with the words dos, más, and los.



Task 5: Omitting one syllable

Instructions:

"Now I will teach you a different activity. Look at the drawings. Please tell me their names.

Example:

The evaluator should make sure the participant knows the names of all the pictures, if not, the evaluator should teach them. "This is a copa, a pipi, a gato, a pala and a zapato. Now we will say the names of the words without saying the sound /*pa*/. We will remove /*pa*/ from each word. If we take /*copa*/ and we remove /*pa*/, we will only say /*co*/.

Task 6th: Omitting a phoneme

Instructions:

"This activity is very similar to the one we did before. Look at the pictures and tell me their names.

Example:

The evaluator should make sure the participant says the right name, otherwise the evaluator should teach the words. "Here we have a mesa, a muela, a mono, a moto, and a bed". The evaluator should exaggerate the mmmmm to facilitate the identification. "Now we will say the name of these pictures without saying the sound /*m*/. When we delete the sound /*m*/ we will change it for a gesture of silence. If we take /*mesa*/, and delete the sound /*m*/, we can only say "(gesture)…esa". The evaluator should do the same thing with the other words.

Appendix C: Working memory test

9. Spatial Span

DISCONTINUE RULE:
After scores of 0 on both trials of any item. For both Spatial Span Forward & Spatial Span Backward, administer both trials of each item even if Trial 1 is passed.

RECORDING:
All responses verbatim

SCORING RULE:
0–1 pt. for each trial

Spatial Span Forward

Item/Trial			Response	Score 0 or 1
1.	Trial 1	3 – 10		✓
	Trial 2	7 – 4		✓
2.	Trial 1	1 – 9 – 3		✓
	Trial 2	8 – 2 – 7		✓
3.	Trial 1	4 – 9 – 1 – 6	✓	
	Trial 2	10 – 6 – 2 – 7	✓	
4.	Trial 1	6 – 5 – 1 – 4 – 8	✓	
	Trial 2	5 – 7 – 9 – 8 – 2	5728	
5.	Trial 1	4 – 1 – 9 – 3 – 8 – 10	4 1 9 3 8 10	
	Trial 2	9 – 2 – 6 – 7 – 3 – 5	9 2 6 7 8 3	
6.	Trial 1	10 – 1 – 6 – 4 – 8 – 5 – 7	10 1 7 5 9 8 2 4	
	Trial 2	2 – 6 – 3 – 8 – 2 – 10 – 1	2 6 3 7 2 10 2	
7.	Trial 1	7 – 3 – 10 – 5 – 7 – 8 – 4 – 9		
	Trial 2	6 – 9 – 3 – 2 – 1 – 7 – 10 – 5		
8.	Trial 1	5 – 8 – 4 – 10 – 7 – 3 – 1 – 9 – 6		
	Trial 2	8 – 2 – 6 – 1 – 10 – 3 – 7 – 4 – 9		

Forward Total Score Range = 0 to 16

Spatial Span Backward

Item/Trial			(Correct Response)/Response		Score 0 or 1
1.	Trial 1	7 – 4	(4 – 7)	✓	
	Trial 2	3 – 10	(10 – 3)	✓	
2.	Trial 1	8 – 2 – 7	(7 – 2 – 8)	782	
	Trial 2	1 – 9 – 3	(3 – 9 – 1)	✓	
3.	Trial 1	10 – 6 – 2 – 7	(7 – 2 – 6 – 10)	76210	
	Trial 2	4 – 9 – 1 – 6	(6 – 1 – 9 – 4)	6194	
4.	Trial 1	5 – 7 – 9 – 8 – 2	(2 – 8 – 9 – 7 – 5)	28295	
	Trial 2	6 – 5 – 1 – 4 – 8	(8 – 4 – 1 – 5 – 6)	6458	
5.	Trial 1	9 – 2 – 6 – 7 – 3 – 5	(5 – 3 – 7 – 6 – 2 – 9)		
	Trial 2	4 – 1 – 9 – 3 – 8 – 10	(10 – 8 – 3 – 9 – 1 – 4)		
6.	Trial 1	2 – 6 – 3 – 8 – 2 – 10 – 1	(1 – 10 – 2 – 8 – 3 – 6 – 2)		
	Trial 2	10 – 1 – 6 – 4 – 8 – 5 – 7	(7 – 5 – 8 – 4 – 6 – 1 – 10)		
7.	Trial 1	6 – 9 – 3 – 2 – 1 – 7 – 10 – 5	(5 – 10 – 7 – 1 – 2 – 3 – 9 – 6)		
	Trial 2	7 – 3 – 10 – 5 – 7 – 8 – 4 – 9	(9 – 4 – 8 – 7 – 5 – 10 – 3 – 7)		
8.	Trial 1	8 – 2 – 6 – 1 – 10 – 3 – 7 – 4 – 9	(9 – 4 – 7 – 3 – 10 – 1 – 6 – 2 – 8)		
	Trial 2	5 – 8 – 4 – 10 – 7 – 3 – 1 – 9 – 6	(6 – 9 – 1 – 3 – 7 – 10 – 4 – 8 – 5)		

Backward Total Score Range = 0 to 16

Total Score Range = 0 to 32

(Sum Forward Total Score & Backward Total Score)

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Appendix D: Word recognition in Spanish

Prueba 1 Identificación de letras y palabras

Nivel básico: 6 ítemes correctos de numeración más baja
Nivel máximo: 6 ítemes incorrectos de numeración más alta

Calificación 1, 0 Esfuerzo Palabra usada

1 ____ L

2 ____ A

3 ____ O
4 ____ i
5 ____ s
6 ____ B

7 ____ p
8 ____ R
9 ____ N
10 ____ U

11 ____ de

12 ____ es
13 ____ vez
14 ____ pan
15 ____ uno
16 ____ por
17 ____ ver
18 ____ van
19 ____ niño

20 ____ ir
21 ____ usar
22 ____ mejor
23 ____ jueves
24 ____ parte
25 ____ joven
26 ____ decir
27 ____ cual

28 ____ historia
29 ____ tenía
30 ____ llevar
31 ____ quemar
32 ____ página
33 ____ guardar
34 ____ cubierta
35 ____ respuesta

36 ____ ciudad
37 ____ aparato
38 ____ interrogar
39 ____ interesado
40 ____ derretir
41 ____ autoridad
42 ____ práctica
43 ____ silueta

44 ____ vejez
45 ____ majadero
46 ____ desalmado
47 ____ insuficiente
48 ____ precipitar precipor
49 ____ astronomía
50 ____ esencial
51 ____ acrílico

52 ____ melodioso
53 ____ audiencia
54 ____ municipalidad
55 ____ caudaloso
56 ____ cromosoma
57 ____ termostato
58 ____ irregularidad
59 ____ perjuicio

60 ____ almohadón
61 ____ subsidiario
62 ____ desairadamente
63 ____ apóstrofe
64 ____ almibarado
65 ____ deliberadamente
66 ____ calabacear
67 ____ triquiñosis

68 ____ psicosis
69 ____ conjeturador consuegador
70 ____ eufemismo
71 ____ galapaguera
72 ____ justipreciación

73 ____ zaramagullón
74 ____ ignominia
75 ____ resquebrajadizo
76 ____ vitivinicultura

Respuestas correctas (0-76)

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2

Prueba 1 Identificación de letras y palabras
Tabla de puntuaciones
Para las *Respuestas correctas*, redondee la línea completa.

Respuestas correctas	AE(Est)*	GE(Est)*
0	<2-5	<K.0
1	3-2	<K.0
2	4-1	<K.0
3	4-10	K.0
4	5-3	K.2
5	5-6	K.3
6	5-7	K.4
7	5-9	K.5
8	5-10	K.5
9	5-11	K.6
10	6-0	K.7
11	6-1	K.7
12	6-2	K.8
13	6-3	K.9
14	6-4	1.0
15	6-5	1.0
16	6-6	1.1
17	6-7	1.2
18	6-7	1.3
19	6-8	1.4
20	6-10	1.4
21	6-11	1.5
22	7-0	1.6
23	7-0	1.7
24	7-1	1.8
25	7-2	1.9
26	7-3	1.9
27	7-4	2.0
28	7-5	2.1
29	7-6	2.2
30	7-7	2.2
31	7-8	2.3
32	7-9	2.4
33	7-10	2.5
34	7-11	2.6
35	8-0	2.8
36	8-2	2.9
37	8-3	3.0
38	8-5	3.2
39	8-7	3.3
40	8-8	3.4
41	8-10	3.6
42	9-0	3.7
43	9-2	3.8
44	9-4	4.0
45	9-7	4.2
46	9-9	4.3
47	10-0	4.5
48	10-3	4.7
49	10-6	4.9
50	10-9	5.1
51	11-0	5.4
52	11-3	5.6
53	11-6	5.8
54	11-9	6.1
55	12-1	6.4
56	12-4	6.6
57	12-7	6.9
58	12-10	7.2
59	13-1	7.5
60	13-5	7.8
61	13-8	8.2
62	14-0	8.5
63	14-4	8.9
64	14-9	9.4
65	15-2	9.9
66	15-8	10.6
67	16-4	11.3
68	17-1	12.3
69	18-1	13.8
70	19	15.2
71	20	17.7
>71	>22	>18.0

*El software del programa de calificación provee los valores precisos de las puntuaciones estimadas de AE y GE.

Appendix E: Word recognition in English

Test 1 Letter-Word Identification

Basal: 6 lowest correct
Ceiling: 6 highest incorrect

Score 1, 0 effort Actual word

1 ____ P

2 ____ E

3 ____ B
4 ____ C

5 ____ k
6 ____ r

7 ____ A
8 ____ D
9 ____ G

10 ____ cat
11 ____ m
12 ____ h
13 ____ t
14 ____ b

15 ____ car
16 ____ on

17 ____ to
18 ____ dog
19 ____ in
20 ____ can
21 ____ as
22 ____ get
23 ____ was
24 ____ have

25 ____ they
26 ____ when
27 ____ there thee
28 ____ must
29 ____ about
30 ____ only
31 ____ part
32 ____ could

33 ____ because
34 ____ knew
35 ____ own On
36 ____ whole
37 ____ against
38 ____ sentence
39 ____ island
40 ____ decide

41 ____ since
42 ____ distance
43 ____ usually
44 ____ scientist
45 ____ bounties
46 ____ fierce
47 ____ experience
48 ____ moustache

49 ____ achieved
50 ____ tremendous
51 ____ systematic
52 ____ urged
53 ____ ancient
54 ____ obviously
55 ____ sufficient
56 ____ particularly

57 ____ domesticated
58 ____ interpretation
59 ____ therapeutic
60 ____ bouquet
61 ____ significance
62 ____ provincial
63 ____ aeronautic
64 ____ conspicuous

65 ____ diacritical
66 ____ deficiencies
67 ____ pituitary
68 ____ trivialities
69 ____ debutante
70 ____ magnanimous

71 ____ homogenization
72 ____ indissolubly
73 ____ picaresque
74 ____ ubiquitous
75 ____ argot
76 ____ satiate

Number Correct (0–76)

Encircle row for the Number Correct.

Number Correct	AE (Est)*	GE (Est)*
0	<2-0	<K.0
1	2-0	<K.0
2	3-0	<K.0
3	3-8	<K.0
4	4-2	<K.0
5	4-5	<K.0
6	4-8	<K.0
7	4-11	<K.0
8	5-1	K.1
9	5-3	K.2
10	5-4	K.2
11	5-6	K.3
12	5-8	K.4
13	5-9	K.5
14	5-11	K.6
15	6-0	K.7
16	6-2	K.8
17	6-3	K.9
18	6-4	1.0
19	6-5	1.1
20	6-6	1.2
21	6-7	1.2
22	6-8	1.3
23	6-9	1.4
24	6-10	1.5
25	6-11	1.5
26	7-0	1.6
27	7-0	1.7
28	7-1	1.8
29	7-2	1.8
30	7-3	1.9
31	7-4	2.0
32	7-5	2.1
33	7-6	2.2
34	7-7	2.2
35	7-8	2.3
36	7-9	2.4
37	7-10	2.5
38	7-11	2.6
39	8-0	2.7
40	8-1	2.8
41	8-2	2.9
42	8-4	3.0
43	8-5	3.1
44	8-6	3.3
45	8-8	3.4
46	8-10	3.5
47	9-0	3.7
48	9-2	3.8
49	9-4	4.0
50	9-7	4.2
51	9-10	4.4
52	10-1	4.6
53	10-4	4.8
54	10-8	5.1
55	11-0	5.3
56	11-4	5.6
57	11-8	5.9
58	12-0	6.3
59	12-4	6.7
60	12-9	7.1
61	13-1	7.5
62	13-6	8.0
63	14-0	8.5
64	14-6	9.1
65	15-1	9.8
66	15-9	10.6
67	16-6	11.6
68	17-5	12.7
69	18-4	14.1
70	19	15.4
71	20	17.3
72	21	>18.0
>72	>22	>18.0

*AE and GE are estimates of the precise values provided by the software scoring program.

Appendix F: One back words

palabra	noticia	cristal	mundo
cama	dueño	proceso	entrada
secreto	torno	proceso	artista
rostro	ciudad	sonrisa	artista
espalda	familia	mentira	opinión
espalda	familia	precio	columna
lengua	actor	cuello	leche
ciencia	causa	mercado	actitud
capital	especie	maestro	actitud
patria	amistad	maestro	fuego
vientre	libro	dedo	humor
mano	banco	sistema	signo
paisaje	remedio	gato	cielo
tono	remedio	humo	plaza
peso	perro	juicio	plaza
ella	lugar	tema	guardia
ella	empresa	corazón	policía
vida	marco	enemigo	hermano
vida	materia	enemigo	carta
persona	colegio	lectura	memoria
lluvia	colegio	idea	interés
escuela	militar	esquina	interés
escuela	viaje	cola	pared
risa	ocasión	caballo	período
soledad	árbol	máquina	mujer
energía	silla	máquina	grupo
aspecto	silla	tierra	iglesia
negocio	técnica	función	iglesia
negocio	calor	olor	pintura
ejemplo	ruido	fortuna	sitio
hombre	terreno	destino	siglo
calidad	terreno	destino	gente
versión	aparato	rato	defensa
niño	ventana	mito	defensa
niño	pueblo	gris	coche
boca	asiento	barrio	hermana
palacio	asiento	barrio	lucha
isla	pasillo	base	virus
isla	mente	carrera	virus
caja	tarea	cerebro	botella
cultura	tarea	amor	nombre
arte	nariz	antiguo	frase
control	monte	antiguo	respeto

Appdendix G: One-back paradigm symbols

Symbols used for the symbol condition on the one back paradigm

Appendix H: Words from Reading Verification Task

ventana	título	cuerpo	vino
dama	impulso	color	orden
artista	partido	crítica	deje
fama	entrada	envidia	rama
raza	ocasión	playa	aquel
frente	arma	iglesia	abuela
policía	interés	poesía	precio
casa	nivel	pareja	materia
curso	oído	mando	máquina
aire	dolor	sistema	presión
sentido	humano	deseo	puerta
esposa	cuello	relato	agua
cuadro	plaza	intento	juez
pelo	alguien	miseria	línea
capital	hierro	vientre	rica
ayuda	objeto	noche	muro
fiesta	pozo	copa	patio
culpa	visión	mármol	mapa
papá	boda	matar	grupo
meta	caza	risa	tren
capa	banco	reina	ropa
final	total	salud	peligro
palo	doña	persona	edad
física	hambre	música	fecha
mesa	rostro	campo	régimen
cine	gloria	lugar	opinión
vuelta	enfermo	error	ciudad
dinero	quitina	espalda	riesgo
bosque	semana	sangre	silla
terreno	patria	razón	especie
punto	nave	altura	noticia
gota	viaje	humor	cara
palacio	mente	pueblo	colegio
monte	calle	olor	escena
asiento	texto	maestro	celular
poema	suerte	gato	lluvia

Appendix I: Demographics and Inclusion criterion tests

NUMBER	GROUP	GENDER	HANDEDNESS	CONSENT	COUNTRY OF BIRTH	TIME IN USA
756	comparison	male	right	yes	Chile	10
760	comparison	male	right	yes	Dominican Republic	40
762	comparison	female	right	yes	Dominican Republic	20
763	comparison	female	right	yes	Dominican Republic	3
765	comparison	male	right	yes	Dominican Republic	3
766	comparison	male	right	yes	Dominican Republic	25
768	comparison	male	right	yes	Dominican Republic	0
771	comparison	female	right	yes	Mexico	10
769	study	female	right	yes	Mexico	15
770	study	female	right	yes	Mexico	10
785	study	female	right	yes	Mexico	20
786	study	male	right	yes	Mexico	13
787	study	male	right	yes	Dominican Republic	16
788	study	male	right	yes	Mexico	13
789	study	female	right	yes	Mexico	14
792	study	male	right	yes	Mexico	16

NUMBER	AGE	LANGUAGE	LITERACY LANGUAGE	ENGLISH PROFICIENCY	HIGHEST DEGREE	REASON TO LEAVE SCHOOL
756	30	Spanish	Spanish	do not speak English	College	N/A
760	64	Spanish	Spanish	average	12th grade	N/A
762	57	Spanish	Spanish	average	12th grade	N/A
763	55	Spanish	Spanish	not proficient	12th grade	N/A
765	40	Spanish	Spanish	average	College	N/A
766	56	Spanish	Spanish	average	College	N/A
768	39	Spanish	Spanish	do not speak English	College	N/A
771	50	Spanish	Spanish	average	College	N/A
769	50	Spanish	N/A	not proficient	N/A	illnes
770	52	Spanish	N/A	do not speak English	N/A	family
785	35	Spanish	N/A	do not speak English	N/A	family
786	45	Spanish	N/A	do not speak English	N/A	family
787	27	Spanish	N/A	not proficient	1st grade	other
788	37	Spanish	N/A	do not speak English	N/A	family
789	33	Spanish	N/A	do not speak English	N/A	family
792	40	Spanish	N/A	do not speak English	N/A	family

NUMBER	FLUENT SPANISH	EFFORTFUL SPANISH	FLUENT ENGLISH	EFFORTFUL ENGLISH	PHONOLOGICAL AWARENES	SPATIAL WORKING MEMORY
756	76	76	39	39	29	11
760	71	71	33	33	26	14
762	76	76	32	32	23	9
763	76	76	34	34	28	12
765	75	75	36	36	28	15
766	74	74	41	41	25	12
768	74	74	0	0	23	12
771	76	76	40	40	29	10
769	17	61	7	7	14	8
770	24	62	6	6	14	15
785	18	61	15	15	18	7
786	28	74	22	22	16	13
787	19	47	21	21	15	13
788	29	69	13	13	14	13
789	19	47	12	12	18	14
792	21	46	14	14	17	12

Appdendix J: Consent Forms

Title of the project: N170 visual word specialization on implicit and explicit reading tasks in Spanish speaking adult neoliterates

DESCRIPTION OF THE RESEARCH: You are invited to participate in a research study on how adults who learned to read and write in adulthood carry out reading tasks. We call people who learned to read and write as adults, "neoliterates", which means "new readers". Sometimes adult neoliterates read differently than people who learned to read and write in childhood. This can make it hard for them to understand the meaning of what they read. We want to find out how neoliterates learn to recognize words fast. Recognizing words fast is an important skill in reading. The best way for us to find out more about this is for us to measure how your brain responds to different reading tasks.

PROCEDURES: In this research project, you will be asked to come to the Neurocognition of Language Laboratory and take part in a brain data collection session, and a simple testing session. Today, if you want to take part, we will ask you to be in the lab for one to two hours. We will first ask you some questions about how and when you learned to read and write, and how skilled you are at reading and writing.

After that, we will get ready to record your brain activity. The recording of brain data, or electroencephalography (EEG), involves the following steps. Your head size will be measured and you will have a "net" placed on your head. The net contains sensors inside small sponges, that sit directly on the scalp. The sponges are first soaked in a weak salt solution (potassium chloride) which helps pick up small electrical signals. The very small signals that tell us about brain activity are recorded through the sensors.

When the brain data collection net is on your head, we will ask you to sit in a special room where there is a computer screen. We will make sure that the net is working properly, and then we will begin the reading tasks.

In the first task, while we record EEG, you will see symbols and words. You will be asked to press a button whenever you see two of the same. In the second task, you will read and listen to some words. You will be asked to push one button to say if the word you see is the same as the word you hear. If the words are different, we will ask you to press a different button. There will be a chance to practice these tasks before you begin.

After you finish with the EEG part, we will ask you to take two tests: one to assess the way you process sound (phonological awareness test); and one to assess the way you remember patterns (working memory test). In addition, we will ask you to read some words. Then you will be finished with the experiment.

RISKS AND BENEFITS:

The same as with any recording of activity in the body, there is a small risk of electric shock. This risk is about the same as the risk in using a toaster or a hair dryer. We keep this risk as low as possible by using a special piece of equipment to isolate our recording equipment from the mains electricity, and by making sure that you are never connected to earth ground (which means that you cannot form part of an electrical circuit).

There is a risk that the skin on your scalp or face, which can be very sensitive, might be irritated by the sensors being placed on your head. We make this risk smaller by carefully choosing the kind of salt solution used to soak the net, to be as gentle on the skin as possible.

There is also a small risk of skin infection. We keep this risk as small as possible by always carefully disinfecting the sensor net before it is used.

The sensor net will be wet when we put it on your head, and this might be uncomfortable at first. However, towels are provided to keep you comfortable and to protect your clothing.

The tasks we will ask you to do can be repetitive, and you may find them a little boring and/or difficult to complete. However, you can take breaks during the experiment and training, and carry on only when you feel ready.

There is no direct benefit to you for taking part in the study. We hope that our study will help us understand more about how people learn to read when they are adults. One day we hope that this better understanding will help us to develop ideas about more effective ways to teach reading to adults.

If you feel uncomfortable or concerned with the net, the tasks, or any part of your time in the lab, please feel free to ask questions and talk to the experimenter.

If at any time you do not wish to continue taking part in the study, we will stop and take a break. After a while, you might decide to carry on, and that is fine; however, if you do not want to continue, that will also be fine, and there will be no penalty to you for deciding not to carry on. You can stop taking part in the study AT ANY TIME.

REIMBURSEMENT
We will make a small cash payment of $25 to thank you for your time and participation, at the end of the study. In addition, we will cover transportation costs by providing you with a MetroCard, valid for a round trip ($4.50 dollars).

CONFIDENTIALITY:

Your privacy is VERY important to us, and we are very careful to protect your identity.

Computer files are stored on password-protected computers that can only be accessed by members of the research team. Data files are stored only with numbers, not names. The only place where your name and your identifying number will be stored together, is on this consent form. You will be given a copy of this form to keep, and the only other copy will be stored in a locked filing cabinet in the office of the study's faculty sponsor, Prof. Karen Froud.

When we report results from our studies (e.g. at meetings to discuss research, or in professional journals), we usually report results from many people together, as averages. We NEVER use names when reporting or discussing data.

TIME INVOLVEMENT: Your participation will take approximately one to two hours.

HOW WILL RESULTS BE USED: The results of the study will be used in the dissertation of the principal investigator, in professional reports for publication in journals, and for presentation at professional and academic conferences.

CONSENT:

I agree that I ____[Name] am willing to take part in the study entitled N170 visual word specialization on implicit and explicit reading tasks in Spanish speaking adult neoliterates

I have had an opportunity to ask questions about the study, and I understand what is involved.

Signed: ____

Date (mm/dd/yyyy): _______//_______//_________

Please also sign the Participants' Rights form (attached). Teachers College, Columbia University

PARTICIPANTS' RIGHTS

*** The researcher will read the participatn's rights out loud, asking the participant to answer yes or no.**

Principal Investigator:
____

Research Title: ____

Please respond yes or no to these affirmations.

- I have read and discussed the Research Description with the researcher. I have had the opportunity to ask questions about the purposes and procedures regarding this study.
- My participation in research is voluntary. I may refuse to participate or withdraw from participation at any time without jeopardy to future medical care, employment, student status or other entitlements.
- The researcher may withdraw me from the research at his/her professional discretion.
- If, during the course of the study, significant new information that has been developed becomes available which may relate to my willingness to continue to participate, the investigator will provide this information to me.
- Any information derived from the research project that personally identifies me will not be voluntarily released or disclosed without my separate consent, except as specifically required by law.
- If at any time I have any questions regarding the research or my participation, I can contact the investigator, who will answer my questions. The investigator's phone number is (347)207-8517.
- If at any time I have comments, or concerns regarding the conduct of the research or questions about my rights as a research subject, I should contact the Teachers College, Columbia University Institutional Review Board /IRB. The phone number for the IRB is (212) 678-4105. Or, I can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY, 10027, Box 151.
- I should receive a copy of the Research Description and this Participants' Rights document.
- If video and/or audio taping is part of this research, I ( ) consent to be audio/video taped. I ( ) do NOT consent to being video/audio taped. The written, video and/or audio taped materials will be viewed only by the principal investigator and members of the research team.

- Written, video and/or audio taped materials ( ) may be viewed in an educational setting outside the research

  ( ) may NOT be viewed in an educational setting outside the research.

- My signature means that I agree to participate in this study.

Participant's signature: ________________________________ Date:____/____/____

Name: _____________________________

Investigator's Verification of Explanation

I certify that I have carefully explained the purpose and nature of this research to __________________________________ (participant's name) in age-appropriate language. He/She has had the opportunity to discuss it with me in detail. I have answered all his/her questions and he/she provided the affirmative agreement (i.e. assent) to participate in this research.

Investigator's Signature: ____

Date: ______________________

T E A C H E R S   C O L L E G E

C O L U M B I A   U N I V E R S I T Y

Department of Biobehavioral Sciences

INFORMED CONSENT FORM SUMMARY FOR SPANISH SPEAKER NEOLITERATES EXPERIMENTAL GROUP

This is a summary of the Informed Consent form. You will receive a copy of the form.

You are invited to participate in a research study on how adults who learned to read and write in adulthood carry on reading tasks. Sometimes these people read differently from people who learned to read and write during childhood. We want to find out how neoliterates learn to recognize words fast. The best way for us to find out more about this is for us to measure how your brain responds to different reading tasks.

PROCEDURES: Your participation will consist on three parts:

1. Background questionnaire: We will ask you some questions about when and how you learned to read and write.
2. Brain data collection: We will measure your head, and we will place a “net” on your head. The net contains sensors inside sponges that sit on the scalp. The sponges are first soaked in a weak salt solution that helps pick up electrical signals. We will ask you to sit in a special room where there is a computer screen. We will make sure the net is working and we will begin the task

    In the first task, while we record EEG, you will see symbols and words. You will be asked to press a button whenever you see two of the same. In the second task, you will read and listen to some words. You will be asked to push one button to say if the word you see is the same as the word you hear. If the words are different, we will ask you to press a different button. There will be a chance to practice these tasks before you begin.

3. Phonological awareness test and Working memory test: We will ask you to manipulate the sounds of some words (Phonological awareness test). Also we will ask you to repeat a pattern with your finger (Working memory test).
4. Confirmation test: We will ask you to read some words.

RISKS AND BENEFITS:
There are very small risks of electric shock, irritation, infection, discomfort, and get bored. We diminish these risks by not letting you form part of an electrical circuit, isolate our recordings from the mains electricity, using a kind saline solution, disinfecting the nets before each use, providing you towels and allowing you to take as many breaks as you need.

You can stop taking part of the study at any time.

REIMBURSMENT: $25 dollars plus a MetroCard valid for a round trip.

CONFIDENTIALITY: A number will be assigned to the data from your participation. The results will be shared using the average of many participants, and no names will be used.

PLEASE SIGN THE CONSENT FORM

Confirmation questionnaire

N170 visual word specialization on implicit and explicit reading tasks in Spanish speaking adult neoliterates

I am aware that my participation takes from one to two hours.	Yes	No
I am aware that the researcher will ask questions about how and when I learned to read and write.	Yes	No
I am aware that the researcher will collect data from my brain activity	Yes	No
I am aware about the process of brain data collection: measuring my head, placing the wet net on my scalp, and doing the experiment	Yes	No
I am aware that the experiment will be conducted on a special room on a computer screen	Yes	No
I know that the risk of electric shock is about the same as the risk of using a toaster and hair dryer	Yes	No
I know that there is a small risk of skin irritation due to the sensors being placed on my head	Yes	No
I am aware that the nets are carefully cleaned after each use to prevent infection	Yes	No
I am aware that if the task is too boring or difficult, I can take breaks and carry on when I feel ready	Yes	No
I am aware that I can stop taking part in the study at any time, with no repercussions.	Yes	No
I am aware that I will receive $25 dollars for my participation	Yes	No
I know the data is confidential.	Yes	No
I am aware that the results will be used for the dissertation of the principal investigator, professional reports for publication in journals, and professional and academic conferences	Yes	No

Participant's signature: ____

Date:___________________________________