Early and automatic processing of written Chinese:

Visual Mismatch Negativity studies

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Dedication

In the past four years when I did the doctoral study, my grandfather, Xianyu Wei, passed away in September, 2014 and then my grandmother Mennǚ Zhang in June, 2015. I am very sad to have lost them. I dedicate this thesis to them, my beloved grandparents, for their lifelong hard work in building our family from scratch and their love and sacrifice to the whole family.

谨以此作纪念我的祖父魏仙玉和祖母张门女。

Abstract

Fluent reading entails multiple levels of analysis including orthography, syntax and semantics but is also characterised by fast speed and apparent ease in understanding the various linguistic input. This thesis therefore focuses on the earliness and automaticity of single word recognition, which is a fundamental component of reading process. Exactly when a visual stimulus is recognised as a word and comprehended, and to what extent this is an automatic and not a controlled process, are two of the most debated issues in psycholinguistic research.

A series of six Event-Related Potential (ERP) studies were carried out in this study, with the first five of these investigating Chinese single character words and pseudowords and the sixth investigating Spanish words and word-like strings. The critical ERP component of interest is visual Mismatch Negativity (vMMN), a visual counterpart of the well-documented auditory MMN (Näätänen, Gaillard, & Mäntysalo, 1978). VMMN has recently been demonstrated to be a neural index of automatic processing of not only generic visual features but also written words. To overcome the compounding of physical differences between stimulus conditions, a "same-stimulus" identity oddball paradigm was adopted throughout the studies. The vMMN was computed by comparing the ERP responses to deviant and standard stimuli of the same lexical/semantic category.

It was found that lexical and semantic vMMN effects could be obtained within the first 250 ms after the stimulus onset, even when the critical words were presented briefly and outside of the focus of attention (perifoveally) and participants were instructed to carry out a non-linguistic distraction task, indicating automaticity of processing. The similarity in the timing of these early vMMN responses lends support to parallel processing models of linguistic information processing. In addition, vMMN to changes in lexicality was subject to configurations in the cognitive system, with attention and the magnitude of deviance revealed as two important variables. Language vMMN effects in normal adults as revealed in this thesis may serve as a benchmark for assessing the reading abilities of first or second language readers, as well as of people with linguistic impairments, such as dyslexia.

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Chapter One: General Introduction

Fluent reading is a remarkable human achievement. It is so effortless and reflex-like that normally we take it for granted, suggesting that comprehension in reading may occur instantly and automatically. Despite its rapidity and apparent ease, skilled reading entails mastery of multiple levels of analysis, including orthography, syntax and semantics. In such a complex process, exactly when visual input is recognised as words and comprehended, and to what extent this is automatic, are two of the most debated issues in this area of research. This thesis aims to contribute to these debates by investigating single-character words in Chinese, a non-alphabetic language with very different characteristics to the Indo-European languages usually studied in visual word recognition research.

1.1 Research background

Single word recognition is basic to human reading, which is an intellectual activity fundamental to success in our complex and dynamic modern societies. The various elements and levels of linguistic information, together with the connections among them which are interwoven in a single word, arguably provide the best available micro-model for understanding human reading. Research in this field with fluent readers also provides a baseline for examining how reading occurs, or fails to occur efficiently, in clinical populations with language disorders such as, for example, alexia or dyslexia. In addition, in this research field, two important issues, namely, when and how the lexical and semantic information of a word can be accessed, are of theoretical significance in terms of developing models of language processing.

A long tradition of behavioural experiments and the more recent advent and development of online and neuroimaging techniques such as Event-related Potentials (ERPs), Magnetoencephalography (MEG), and functional Magnetic Resonance (fMRI), have provided rich sources of insight into language processing. Of particular interest to this thesis investigation is previous research using ERPs and MEG, which has provided valuable information on when and how language is processed and reflected neurophysiologically. While there seems to be general agreement that word processing involves basic elements such as visuo-orthographic analysis and semantic retrieval, the exact nature of this processing is still under debate. In terms of the timing of word processing, the arguably traditional or dominant view claims that lexico-semantic processing takes place after about 250 ms (Grainger & Holcomb, 2009; Laszlo & Federmeier, 2014; Pylkkänen & Marantz, 2003). For example, according to Grainger and Holcomb (2009), following perceptual-orthographic analysis and whole word access (before 250 ms), lexico-semantic processing then occurs after 300 ms. However, over the last decade, an increasing amount of evidence suggests a much earlier time-scale for lexico-semantic processing, within 250 ms after the onset of visual word input (Sereno & Rayner, 2003) or the recognition point of auditory words (Pulvermüller, Shtyrov, & Hauk, 2009). Combining behavioural, ERP and MEG techniques in a multi-modal approach, Hauk and colleagues demonstrated that lexical and semantic information can be retrieved almost simultaneously within 200 ms after visual word onset (Hauk, Coutout, Holden, & Chen, 2012). Recently, Shtyrov and MacGregor (2016) have even reported the earliest lexicality effect as early as 70 ms after the onset of the lexical items in the peripheral area. The issue of timing is critical in modelling word recognition (Barber & Kutas, 2007; Hauk et al., 2012; Pulvermüller, Shtyrov, & Hauk, 2009). Understanding the time-course of lexical access and semantic retrieval will contribute to resolving one of the major debates in language science, that is, how different information types, ranging from orthographic to contextual, are processed. Serial/cascaded models argue for different processing steps in sequence (Dell, 1986; Fodor, 1983; Friederici, 2002). These models leave the early neurolinguistic effects "unexplained" (Pulvermüller et al., 2009). In contrast, parallel models (Marslen-Wilson, 1987; Pulvermüller, 2001; Pulvermüller et al., 2009) argue for early and near-simultaneous processing of various information types in auditory and visual modalities.

Related to the above "when" question of word processing is the "how" question, that is, whether lexico-semantic processing is automatic or controlled. Some behavioural and ERP studies, using different paradigms such as the Stroop task (Glaser & Glaser, 1982; Stroop, 1935), masked priming (Naccache & Dehaene, 2001), binocular rivalry (Yang & Yeh, 2011) and continuous flash suppression (Axelrod, Bar, Rees, & Yovel, 2015) seem to suggest that lexico-semantic processing is largely automatic. Others, however, report that lexico-semantic processing is subject to attentional availability and control (Batterink, Karns, Yamada, & Neville, 2010; Brown & Hagoort, 1993). One problem with this question is that, in fact, there is not complete consensus on the definition of automaticity (Kahneman & Treisman, 1984; Kiefer, Adams, & Zovko, 2012; Posner & Snyder, 1975; Schneider & Shiffrin, 1977). While the above studies tend to assume that automatic processing is autonomous and not susceptible to top-down cognitive influences, recent refined theories of automaticity relax this classical definition and emphasise that automatic processing is dependent on higher level factors of task set, attention and intention (Kiefer & Martens, 2010; Moors & De Houwer, 2006). In the current thesis, the classic definition is followed for experimental operationalisation purposes, but emphasis is also given to these factors which can have effects on automatic processing. Exploring the neuronal correlates of automatic processing of language as a high-order cognitive faculty is important for understanding the limits of information-processing automaticity in general.

This thesis attempts to shed new light on the field of visual word recognition by investigating written Chinese single-character words. To do so, a visual Mismatch Negativity (vMMN) paradigm, a design developed in the area of visual object processing, has been borrowed in order to explore the early time course and degree of automaticity in visual word processing. vMMN studies have developed from their auditory counterpart, MMN, which was first discovered by Näätänen and colleagues some decades ago (Näätänen et al., 1978). The MMN is a negative ERP response elicited in oddball experiments by infrequent/deviant acoustic stimuli presented among frequent/standard sounds. It is extracted by subtracting the standard ERPs from the deviant ERPs. MMN is usually observed at frontocentral electrodes, peaking at about 100-250 ms after the onset of acoustic change, regardless of whether subjects attend to or ignore the stimuli (Näätänen, 1990).

Therefore, studies using an MMN design can have advantages in probing into cognitive processes independently of attentional interference and task-related strategies (Pulvermüller, 2007). MMN is not only sensitive to elementary auditory features of the stimuli, such as duration and frequency, but importantly, to changes in speech sounds at various levels of analysis, ranging from phonemes and syllables to lexico-semantics and syntax (for reviews, see Kujala, Tervaniemi, & Schröger, 2007; Pulvermüller & Shtyrov, 2006; Shtyrov & Pulvermüller, 2007. The vMMN effect, similarly, has been elicited by unexpected changes in various visual features, for example, line orientation, object shape and facial expressions. (For a review, see Stefanics, Kremláček, & Czigler, 2014).

Recently, there have also been some attempts to reveal vMMN effects in linguistic studies. For example, Wang and colleagues investigated the extraction of phonology in Chinese character reading (Wang, Liu, Wu, & Wang, 2013; Wang, Wu, Liu, & Wang, 2013). Chinese is a tonal language, with four meaning-bearing lexical tones embedded in the character pronunciation. In Wang, Liu, et al. (2013), homophone characters differing in orthography and semantics were presented in an oddball paradigm to participants who were asked to carry out a colour detection task. Comparing deviants and standards with different lexical tones, vMMN was found at two intervals of 140-200 ms and 230-360 ms. It was argued that vMMN was elicited by violation of lexical tone regularity in the homophones, indicating that tonal information is automatically extracted. In another study, Shtyrov, Goryainova, Tugin, Ossadtchi, and Shestakova (2013) carried out the first attempt to investigate early and automatic lexical processing using a vMMN paradigm.

They briefly presented five oddball blocks of Russian words outside the participants' attentional focus. Each of the five blocks shared the same deviant-standard orthographic contrast. Participants were asked to carry out a primary distraction task in the foveal area. It was reported that real words produced a larger brain response than pseudowords as early as 110 ms after stimulus onset. Both real word and pseudoword deviants were found to elicit vMMNs, at the 100-120 ms and 240-260 ms intervals. However, no interaction between stimulus type (standard vs. deviant) and lexical status (real vs. pseudoword) was found, suggesting that the vMMN was not sensitive to lexicality change. This is not consistent, however, with the above-mentioned auditory MMN studies in which real words were typically found to elicit enhanced MMN effects relative to pseudowords. However, language-related vMMN study is still in its infancy and more studies are needed to clarify the nature and characteristics of language-related vMMN effects.

1.2 The present study

The current project therefore attempts to explore lexico-semantic processing in Chinese by means of a non-attend vMMN design. In this study, five research questions are addressed:

1.2.1 Research question 1

Can the lexicality information of Chinese characters be processed out of attentional focus, i.e. automatically? And if so, how early can this occur?

Since research in the area of language-related vMMN has been so scarce, the first step in this study was to establish whether this component is indeed sensitive to lexical status change. Experiment 1 was therefore designed to address this issue. Real-, pseudo- and non- characters, matched in their overall visual-physical attributes, were prepared. These stimuli were presented outside of attentional focus while participants were instructed to respond in a primary non-linguistic task presented in the middle of the screen.

1.2.2 Research question 2

How are the language-related vMMN effects influenced by factors of magnitude of stimulus change (deviance) and attention?

Based on the positive findings of the language-related vMMN in the first experiment, Experiments 2 and 3 went on to examine how these two factors in influencing vMMN elicitation, in order to better characterise the vMMN effects elicited by linguistic stimuli. The magnitude of difference refers to the degree of change between standard and deviant stimuli in an oddball sequence. In the auditory modality, the amplitude of MMN changes as a function of the magnitude of stimulus change (Näätänen, Paavilainen, Rinne, & Alho, 2007). However, it is not known whether it is also the case for linguistic processing in a vMMN design. Therefore, this factor is investigated in Experiment 2. To investigate attentional influence on linguistic vMMN effects, Experiment 3 directed participants' attentional focus to the critical lexical stimuli. Comparing the results of Experiments 3 and 1 can uncover the effects of attention on vMMN.

1.2.3 Research question 3

Can lexical frequency information be processed without attentional focus and if so, when does this occur?

As a well-established index of lexical access, lexical frequency is one of the most widely-studied variables in visual word recognition. A reader usually has better or faster performance with higher frequency (HF) words than lower frequency (LF) ones, i.e., the word frequency effect (Seidenberg & McClelland, 1989). Previous MMN studies have yielded inconsistent results in the processing lexical frequency information (Alexandrov, Boricheva, Pulvermüller, & Shtyrov, 2011; Wang, Wu, et al., 2013). While Alexandrov et al. reported a larger MMN to HF than LF words in the interval of 140-200 ms, Wang et al. did not find such a frequency effect on MMN in the visual modality. Therefore, Experiment 4 went on to explore the influence of lexical frequency on these early, automatic vMMN effects.

1.2.4 Research question 4

Can the semantic content of Chinese characters be processed without attentional focus and if so, when does this occur?

This question moves the focus of enquiry from lexical access to the semantic processing level. Due to the multifaceted nature of semantics, the question is tackled by examining one specific dimension of word meaning: semantic concreteness. Concrete words are normally recognised faster and remembered better in various psycholinguistic tasks. This processing advantage of concrete over abstract words is termed the concreteness effect (Holcomb, Kounios, Anderson, & West, 1999; Peters & Daum, 2008). While this effect has been extensively studied, there have been few studies examining its possible early presence in a vMMN design. Experiment 5 therefore aimed to address this issue.

1.2.5 Research question 5

Can lexicality information be automatically processed, as indexed by lexical vMMN effects, in an alphabetic language such as Spanish?

Building on the results of Experiment 1, and given the lack of vMMN results so far in alphabetic languages, Experiment 6 was designed to examine whether vMMN effects can be detected in Spanish, thus testing the generalisability of the Chinese results to other languages.

In sum, the present study aims to answer the five questions listed above, which centre on the earliness and automaticity of lexical and semantic processing of written Chinese single-character words. By exploring language-related vMMN effects and the factors that potentially modulate these, hopefully a better understanding of Chinese word reading can be achieved. Given the importance of reading as an intellectual activity fundamental to success in our complex and dynamic modern societies, the current investigation will therefore hopefully contribute key scientific knowledge to research in this field. This research with fluent readers may also provide benchmarks for examining how reading occurs, or fails to occur efficiently, in clinical populations with language disorders such as, for example, dyslexia.

1.3 Structure of the thesis

Following this general introduction, Chapter 2 introduces the two key concepts of automatic and controlled processing before presenting a review of the literature and previous research relevant to this study. It also introduces the ERP technique and briefly describes the relevant well-documented language-related ERP components, with an emphasis on the MMN component in both auditory and visual modalities. In addition, this chapter reviews previous findings on lexico-semantic processing, particularly at the early stages before 300 ms after stimulus onset. Also provided are a brief introduction to aspects of the Chinese language relevant to the experimental design, and an introduction to time-frequency analysis methods. Chapter 3 then describes the general methodology followed in the current project. Chapter 4 reports the series of six experiments carried out to answer the research questions posed. Finally, Chapter 5 provides a summary of all the experimental findings and a comprehensive discussion of the results. This chapter also discusses the limitations of the current thesis and points to possible directions for future study.

Chapter Two: Key Concepts and Literature Review

This chapter is composed of seven parts. Part 1 introduces two important concepts in the current study, automaticity and attentional influence on cognitive processing. Part 2 gives a general introduction to the ERP technique and describes the classic language-related ERP components relevant to this thesis. Part 3 reviews previous studies on lexico-semantic processing, especially at early latencies before 300 ms. Parts 4 and 5 focus on previous language-related MMN studies in the auditory and visual modalities. Part 6 discusses the time-frequency analysis technique, which investigates dynamic brain oscillations in the frequency domain. Part 7 then describes some features of Chinese characters that are pertinent to the research topic and design.

2.1 Automatic processing and attentional influence

Automatic and controlled processes are widely accepted as two basic information processing modes in human information processing (Schneider & Shiffrin, 1977), including language processing (Tartter, 1986). Generally speaking, automatic processes are fast and occur irrespective of human attention, whereas controlled processes demand the subject's conscious awareness and are thus slower. Traditional theories of automaticity postulate that automatic processes should occur without conscious awareness, and be independent of attentional influences and interferences from other cognitive processes. According to Posner and Snyder

(1975), for example, automatic processing can be supported if it occurs "without intention, without giving rise to any conscious awareness, and without producing interference with other ongoing mental activity" (p 56). According to Kahneman and Treisman (1984), strongly automatic processing means "it is neither facilitated by focusing attention on a stimulus, nor impaired by diverting attention from it" (p 42). A similar proposal to this has also been echoed by Pulvermüller and Shtyrov (2006). In reality, however, it is hard to fully agree with these criteria of automaticity considering that attentional resources and task sets are often found to modulate experimental outcomes (Moors & De Houwer, 2006). Therefore, current theories of automaticity tend to acknowledge this and relax the excessively rigid requirements for defining automaticity (Kiefer & Martens, 2010; Moors & De Houwer, 2006; Naccache, Blandin, & Dehaene, 2002). These refined theories claim that high-level factors such as task requirements, attentional levels and subject intentions are important in configuring cognitive systems to enable automatic processing to occur. Therefore, automaticity does not mean absolute independence of attention but is susceptible to top-down attentional influences. Recently, Kiefer and colleagues (Kiefer et al., 2012; Kiefer & Martens, 2010) have developed the Attentional Sensitisation Model in order to provide a general framework for automatic processing. According to this model, visual processing is automatic in the sense that it acts involuntarily. Nevertheless, it is dependent on attentional availability and sensitive to top-down manipulations. In the current study, automatic processing is defined as cognitive processing without conscious attention. However, in order to delineate clearly how attention may affect lexical MMN effects at different stages, in the current study the direction of attention was manipulated either to central distractor stimuli (in Experiment 1) or, in the case of Experiment 3, to the perifoveally-presented lexical stimuli.

2.2 Event-related potentials (ERPs)

ERPs are voltage fluctuations in the electrical activity of the brain, time-locked to the presentation of a sensory stimulus of interest. They reflect the real-time neuroelectrophysiological correlates of specific cognitive processes with a high temporal resolution of milliseconds (Luck & Kappenman, 2011). Thus, the ERP technique can be an ideal tool to probe into the cognitive functions of the brain. ERPs are based on electroencephalography (EEG) which records the continuous electrical activity in the brain with one or more electrodes positioned on the scalp. The voltage fluctuations recorded outside the head originate in the electrical potentials generated in the extracellular fluid as ions flow across cell membranes. The averaged ERPs reflect the postsynaptic activity of neural ensembles- largely the postsynaptic potentials of large groups of cortical pyramidal cells which are synchronously active and with approximately the same orientation perpendicular to the surface of the skull (Luck, 2005a; Nunez & Srinivasan, 2006). Generally, these small changes in brain electric potentials are amplified and averaged to extract the required signal from background EEG activity. As background EEG varies randomly, when averaged, the noise in the electrical signal will be offset. The averaging process can also strengthen the small signals of interest generated from repetitions of stimulus presentations of conditions, i.e., improve the signal-to-noise ratio. The residual waveform can suggest the non-random brain activity specific to a given type of cognitive process. Waveforms are typically characterised by their amplitude (wave peaks and troughs), polarity (positive/negative), latency (the time of maximal amplitude), duration, morphology (wave shape), and spatial topography (as recorded on the scalp). They are generally labelled according to their polarity and peak latencies (e.g., the N400 is a negative deflection with a peak latency around 400 ms following stimulus presentation). ERPs can also be labelled according to the processes they are considered to index (Kappenman & Luck, 2012; Luck, 2005b), for example, MMN is elicited in response to an incoming deviant stimulus compared to an expected auditory stimulus. ERP components can be exogenous and endogenous. Exogenous components refer to those obligatory responses that are determined by the presence of the eliciting event. Usually, these components have relatively shorter latency. For example, in the auditory modality, there is an exogenous component called N100, whose amplitude is sensitive to the sound strength of stimuli. Endogenous components typically reflect entirely task-dependent neural activities (Luck, 2005) and are not related to physical features of stimuli. Examples of such kind of component include contingent negative variation (CNV) or MMN. CNV was first reported by Walter and his colleagues (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). It is a component seen between a warning stimulus and an imperative stimulus which directs the subject to make a behavioural response, reflecting cognitive processes such as expectancy and attention. MMN can be elicited regardless of whether the subject is paying attention to the sequence or not, so this component is often taken to suggest a pre-attentive change detection mechanism independent of attention. In the next section, first, an introduction to several traditional and well-studied ERP components relevant to language processing will be given. Then focus is given to a detailed description of the early language correlates N170 and MMN.

Left Anterior Negativity (LAN) The LAN is a negative-going waveform occurring between 300 and 500 ms post-stimulus, with a distribution recorded at left anterior electrodes. It can be elicited in response to a variety of morpho-syntactic anomalies such as gender or number violations (e.g., Gunter, Friederici, & Schriefers, 2000; Osterhout & Mobley, 1995) or related to increased load in working memory (e.g., Pakulak & Neville, 2010; Sabourin & Stowe, 2008). Additionally, an early left anterior negativity (ELAN) emerges in some studies between 150-200 ms post-stimulus. It can be obtained by word category violation in a phrase structure (Friederici, Pfeifer, & Hahne, 1993). Since ELAN was reported not to be affected by task manipulations and violation probability, it is interpreted to be automatic in nature (Hahne, Schröger, & Friederici, 2002).

N400 Words that violate semantic expectancy typically elicit an increased N400 component (Kutas & Hillyard, 1980). This is a negative-going deflection in comparison with baseline conditions occurring between 300 and 500 post-stimulus, with a central/posterior and bilateral distribution. The N400 amplitude is found to be modulated by context in semantic priming experiments (e.g., Holcomb & Neville, 1990), and by lexical properties such as word frequency (Petten & Kutas, 1990) and phonotactic probability (Kutas & Federmeier, 2000). These studies may suggest that N400 is an indicator of the cost of lexical access rather than the cost of contextual integration (Kutas & Federmeier, 2000; Lau, Phillips, & Poeppel, 2008).

P600 Also known as Syntactic Positive Shift, the P600 is a late ERP component elicited during syntactic processing and is reported more reliably than the E/LAN. The P600 is a positive-going deflection of the waveform for grammatical violations, starting around 500 ms post-stimulus, and typically peaking around 600 ms. The component has been observed in response to a variety of morphosyntactic violations (e.g., Hagoort, Brown, & Groothusen, 1993, sub-categorisation violations (e.g., Osterhout & Holcomb, 1992) and constructions involving syntactic dependencies and garden path sentences where stimuli are unexpected but grammatical (Kaan & Swaab, 2003), leading some researchers to conclude that this component indexes repair and/or reanalysis of sentence structure. The P600 has been argued to be composed of two stages (Carreiras, Salillas, & Barber, 2004; Hagoort & Brown, 2000; Kaan & Swaab, 2003). The early P600 (generally from 500-750 ms) is believed to indicate integration of a new constituent with the previous material (Phillips, Kazanina, & Abada, 2005), while the later stage (from about 750-1000 ms) is typically captured only in the posterior electrodes and may reflect reanalysis and repair processes (Barber & Carreiras, 2005; Osterhout & Mobley, 1995).

2.3 Lexical and semantic processing as indexed by early ERP correlates

2.3.1 Early lexicality effects

As a special type of visual object, print words must be perceptually processed at first in order to distinguish their identity from other types of objects or symbolic forms. An early ERP study found that words and faces elicited more positivity (P100) than other objects as early as 125 ms, suggesting a quick perceptual categorisation process (Schendan, Ganis, & Kutas, 1998). At posterior sites, Hauk and colleagues reported a larger positivity (P100) for longer words and atypical words (defined by positional N-gram values) than shorter words and typical words (Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006; Hauk, Patterson, et al., 2006; Hauk & Pulvermüller, 2004a; Simon, Bernard, Largy, Lalonde, & Rebai, 2004). These studies indicate that at an early latency around 100-150 ms, low-level visuo-perceptual analysis is carried out, as indexed by the P100 component. The absence of any lexicality effect on P100 may also suggest that at this early stage, access to linguistic information has not yet started. However, in a lexical decision experiment by Sereno, Rayner and Posner (1998), consonant strings elicited more positive P100 than words, and pseudowords more positive P100 than words with marginal significance, although no difference of P100 between consonant strings and pseudowords was reported. Nobre and McCarthy (1994) also reported differences in P100 between pseudowords and nonwords which yet did not show amplitude difference from real words. Proverbio, Vecchi, and Zani (2004) however, described a different direction of result, with less positivity in letter strings than words and pseudowords. In a masked Reicher-Wheeler task (Reicher, 1969; Wheeler, 1970) to investigate the word and pseudoword superiority effect, Coch and Mitra (2010) found orthographically irregular letter strings (nonwords) yielded larger P100 than either words or pseudowords. In another study where subjects were asked to distinguish between words and pseudowords matched in length, Segalowitz and Zheng (2009) found a fine-tuned lexicality effect at P100 (94-114 ms) with more positivity in words than pseudowords. They also found this enhanced positivity of words independent of semantic priming context. The presence of the P1 lexicality effect in these studies seems to suggest that lexical processing can onset very early (Sereno & Rayner, 2003). Taken together, previous studies have been inconsistent in revealing early lexicality effects as reflected by the P100 component. In particular, in a masked priming paradigm which may limit attentional bias in lexical processing, Martin, Nazir, Thierry, Paulignan, and Démonet (2006) did not find sensitivity of P100 to lexical status manipulation, in contrast to the positive findings in Coch and Mitra (2010). The inconsistent findings on P100 may be attributed largely to methodological issues. For example, in Martin et al. (2006) only two stimulus conditions were examined in comparison with four conditions in Coch and Mitra (2010). Stimuli configurations also largely differed among relevant studies in terms of letter string length (four in Martin et al, 2016, five in Coch and Mitra, 2010 and four to six in Sereno et al., 1998 etc.); presentation duration (345 ms in Sereno et al., 1998; 500 ms in Nobre and McCarthy, 1994 etc.). In addition, experimental tasks and paradigms varied across the studies. While Sereno et al. (1998) and Hauk et al. (2004) adopted the simple lexical decision task, Nobre and McCarthy (1994) used a semantic categorisation task and Coch and Mitra (2010) asked participants to identify the correct initial letter of a masked letter string. Therefore, it is likely that any one of these methodological factors or a combination of the factors might be responsible for the observed differences in results among the above studies.

Orthographic processing at different levels is also reflected in a slightly later ERP component called N170, with a peak latency between 140 and 200 ms, mostly present in occipital-temporal or parietal regions. Using positron emission tomography (PET), some studies have found this area (also known as the “visual word form area”, VWFA) is particularly sensitive to the processing of “orthographic regularities” such that real and pseudo- words are more activated than nonwords or false fonts (Petersen, Fox, Posner, Mintun, & Raichle, 1989; Petersen, Fox, Snyder, & Raichle, 1990). The orthographic characteristics were also found to be independent of variations of visual features such as colour, font, size and case (for a review, see McCandliss, Cohen, & Dehaene, 2003). A number of ERP studies have investigated orthographic specialisation in VWFA and have associated N170 with abstracting orthographic information rather than simply detecting elementary visual features of letters or letter strings (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Coch & Meade, 2016; Coch, Mitra, & George, 2012; Compton, Grossenbacher, Posner, & Tucker, 1991; Grossi & Coch, 2005; McCandliss, Posner, & Givon, 1997; Simon et al., 2004). Characterising these studies, however, is some inconsistency in the direction of the N170 effects to letter strings and words/pseudowords. Some studies have reported that orthographic stimuli elicited more negative N170 than non-letter stimuli such as shapes and symbols (Bentin et al., 1999; Coch & Mitra, 2010; Simon et al., 2004). For example, in a visual feature detection task, Bentin et al. (1999) found a left occipito-temporal N170 which was larger for orthographic (words, pseudowords and consonant strings) than for non-orthographic stimuli (alphanumeric symbols and forms). While Bentin et al. (1999) did not find differences between real words, pseudowords and consonant strings, others have reported more negativity in real words and pseudowords than in random letter strings (Coch & Mitra, 2010; Martin et al., 2006) and still others have demonstrated an even finer-grained difference between real and pseudo- words in normal adults, with more negativity in real meaningful words (Coch & Meade, 2016; Mahé, Bonnefond, Gavens, Dufour, & Doignon-Camus, 2012) (Table 3). There are reports suggesting the inverse effect: a larger N170 to consonant strings than to words (Compton et al., 1991; McCandliss et al., 1997). Hauk and colleagues, in contrast, reported more negativity in pseudowords than real words (Hauk, Patterson, et al., 2006).

The inconsistent patterns of result may be attributed to several factors such as type of participants and stimuli. The different tasks implemented in these studies may also be one of the reasons. Indeed, the sensitivity of task type to N170 elicitation is also evidenced in a previous study (Compton et al., 1991). Compton et al. compared N170 (as well as other components) in four different tasks of passive perception, thick letter detection, lower case letter search and lexical decision. The authors found larger N170 to consonant strings than to words across the first three tasks but a reversal of the effect direction in the fourth task. Recently, several studies have demonstrated fine-tuned lexical processing, with larger N170 effect for words than pseudowords (Coch & Meade, 2016; Mahé et al., 2012; Maurer, Brandeis, & McCandliss, 2005). In a visual lexical decision (LDT) task, Mahé et al. (2012) found a lexicality effect with low-frequency word eliciting significantly larger left-lateralised N170 than pseudowords, and both real and pseudowords larger N170 than nonwords. A similar result was also reported by Coch and Meade (2016) using a semantic categorisation task where high-frequency words yielded larger N170 than pseudowords. Due to task differences, participants may employ various strategies which arguably induce disparity of results. For example, Bentin et al. (1999) designed a string size judgment which may demand global attention to the string while an arguably more local focus may be needed in the Compton et al.'s (1991) letter feature (lower case letter/thick letter) detection task.

To sum up, across the array of studies, overall, a general pattern emerges. There is larger N170 for words and word-like stimuli than symbols in normal adult readers, indicative of N170 as a neural marker for reading expertise. However, different tasks might confound word form processing per se. Hence, it is unclear to what extent lexical information can be processed automatically, regardless of the tasks imposed.

In addition to the above P100 and N170 components, there are other electrophysiological markers of lexical processing with a relatively late peak latency such as the recognition potential (RP, Rudell, 1992) and N250 (Holcomb & Grainger, 2007). RP is a negativity usually peaking around 200-250 ms with a left posterior scalp distribution (Rudell, 1992). RP is usually acquired in a paradigm of rapid steam stimulation where centrally displayed stimuli were presented with a short stimulus onset asynchrony (SOA) of around 200 ms and an interstimulus interval (ISI) of 0 ms. It was reported that RP was largest for words, smaller for pseudowords, and smallest for non-orthographic nonwords (Martín-Loeches, Hinojosa, Gómez-Jarabo, & Rubia, 1999). With a similar latency as RP, i.e., around 250 ms, N250 is another negative going component normally found in combined masked priming and ERP studies (Holcomb & Grainger, 2007). It was first reported to be sensitive to orthographic similarity (Carreiras, Duñabeitia, & Molinaro, 2009; Holcomb & Grainger, 2007). It was shown that the component could be influenced by top-down lexical information (Duñabeitia, Molinaro, Laka, Estévez, & Carreiras, 2009).

2.3.2 Early frequency effects

One of the most widely-studied psycholinguistic variables in visual word recognition is lexical frequency. It has been well established that a reader usually has better or faster performance with higher frequency (HF) words than lower frequency (LF) ones (Coltheart, Curtis, Atkins, & Haller, 1993; Seidenberg & McClelland, 1989). A number of ERP and MEG studies have been conducted to investigate the neurophysiological correlates of this effect (Embick, Hackl, Schaeffer, Kelepir, & Marantz, 2001; King & Kutas, 1998; Rugg, 1990). For example, Embick et al. described an MEG component (M350) whose latency of approximately 350 ms reflects lexical frequency effect in a lexical decision task. Rudell (1999) reported an earlier RP latency for HF than LF words (266 vs. 292 ms).

In contrast to the above studies documenting relatively late effects of lexical frequency processing, a number of studies have reported that effects can occur early (within 250 ms), typically after the surface word form features (such as, word length, typicality/N-gram frequency) are processed at around 100 ms. In a lexical decision experiment by Sereno, Rayner, and Posner (1998), the authors observed a lexical frequency effect at early N100 (132 ms), with high-frequency words eliciting smaller negativity than low-frequency ones. A similar result is also found in Mahé et al. (2012) who reported a frequency effect (Table 3) on N100 in the interval of

135-225 ms (but see Simon, Petit, Bernard, & Rebaï, 2007). Using a linear regression approach, Hauk, Davis, et al. (2006) found the frequency effect commenced as early as 110 ms.

The early frequency effect has also been found to be affected by other factors, in particular, word length and preceding context. For example, in an MEG study by Assadollahi and Pulvermüller (2001), the authors described an interaction between frequency and word length. For short words, the lexical frequency effect (stronger responses for LF than HF words) occurred as early as 120 ms while for long words it was delayed till 225 ms. Sereno, Brewer, and O'Donnell (2003) investigated how sentence context may interact with early lexical frequency processing. They found both frequency and context effects as early as 132-192 ms. LF word recognition was facilitated (though marginally) in a biasing context. Ambiguous words in a neutral context behaved more like HF words while in a subordinate-meaning-biasing context, their LF/subordinate meaning was activated accordingly. A similar result was also confirmed in a later study (Penolazzi, Hauk, & Pulvermüller, 2007) where the authors found effects as early as a 110-130 ms interval, and each of the two variables of frequency and semantic cloze probability interacted with length, such that the early lexical effect and semantic integration took effect at the level of short words but not for long words. These findings seem to suggest that early neurolinguistic effects are sensitive to stimulus variance (for a discussion see Pulvermüller, 2007), therefore to obtain the transient early effect, all stimulus items should be matched to lower their variance as much as possible. This stimulus variance factor might also account for the lack of early effects in many other earlier studies (e.g., Kutas & Hillyard, 1980) where insufficient consideration was reportedly given to strict matching of stimuli.

2.3.3 Semantic effects

A wide range of studies has found that concrete and abstract words are processed in different ways. Concrete words are normally recognised faster and remembered better in various psycholinguistic tasks. This processing advantage of concrete over abstract words is termed the concreteness effect (e.g., Peters & Daum, 2008; Strain, Patterson, & Seidenberg, 1995). A number of theories have been put forward to explain this effect. One of these theories is called the Dual Coding theory. It argues that in contrast to the single verbal processing route evoked by abstract words, there are two routes, one verbal and the other imagery, for concrete words, resulting in a privilege in processing (Paivio, 1991; Paivio & Begg, 1971). In contrast, the Context Availability theory posits that in a shared semantic system, concrete words are better responded to because they are more easily integrated into the context than abstract words, an effect which may be remedied with supportive context (Schwanenflugel & Shoben, 1983; Schwanenflugel & Stowe, 1989). Still, another theory, the Revised or Extended Dual Coding theory, proposes that concrete words have more semantic activation in the verbal system and more contribution from mental imagery (Kounios & Holcomb, 1994; Levy-Drori & Henik, 2006). That is, in comparison with the standard DC theory, the revised version goes further in claiming a new difference between concrete and abstract words even in the verbal system, which, however, is argued to be similar for the two category of words in the standard theory.

In recent decades, a number of neuroimaging studies using fMRI and PET have also evidenced differences in processing concrete and abstract words (for reviews, see Binder, 2007; Pexman, Hargreaves, Edwards, Henry, & Goodyear, 2007; Wang, Conder, Blitzer, & Shinkareva, 2010). According to a meta-study involving more than 300 participants (Wang et al., 2010), concrete words have more activations in the left ventral temporal cortex, bilateral posterior cingulate gyrus and left inferior parietal lobes, which are associated with visual features and various conceptual integrations. Abstract words tend to be activated more in the middle/superior part of left anterior temporal lobe (ATL) and the left inferior frontal gyrus (IFG), which are claimed to play an important role in verbal word associations and strategic control of semantic processing respectively. Some neuroimaging studies have suggested that concrete word processing engages a large number of networks linked with the specific sensory-motor properties of the item (For reviews, see Binder, Desai, Graves, & Conant, 2009; Martin, 2007). In contrast, some studies converge in showing that abstract words engage perisylvian and prefrontal areas to a greater degree than concrete words (Binder et al., 2009; Goldberg, Perfetti, Fiez, & Schneider, 2007). Overall, the findings are quite diverse, most likely resulting from differences in stimuli, task types as well as types of analyses. Using ERPs, most studies seem to show a relatively consistent picture in terms of N400 elicitation. Across a variety of tasks such as explicit abstractness/imageability judgment and LDT, concrete words tend to elicit larger N400 than abstract words, with a topographical distribution focusing on posterior and anterior areas (Tolentino & Tokowicz, 2009; Tsai et al., 2009; West & Holcomb, 2000). For example, in an LDT task, Zhang, Guo, Ding, and Wang (2006) investigated the neural dynamics of concrete and abstract Chinese words. Their findings replicated the typical concreteness N400 effect reported in other ERP studies (e.g., West & Holcomb, 2000), with more negative N400 in the latency of 300-500 ms to concrete than abstract Chinese nouns. Interestingly, the authors also observed an early main effect of concreteness at 200-300 ms, suggesting an early activation of semantics. This early semantic onset was discussed with a reference to differences between Chinese and western languages. Chinese characters, the origins of which were largely pictographic, still feature a strong connection between orthography and meaning and the absence of grapheme-phoneme correspondence (Wang, 2011; Zhang, Xiao, & Weng, 2012, but see Perfetti, Liu, & Tan, 2005) , which contrasts Chinese with typical alphabetic languages such as English and Spanish. So this direct link between word form and meaning may lead to early semantic processing in an LDT task. In addition, Zhang et al (2006) found verbs and nouns had different topographical patterns. The noun concreteness effect featured a whole-head distribution, while for verbs only left centro-parietal sites were activated. In two tasks with different depths of semantic processing, lexical decision and semantic relatedness, Tsai et al. (2009) also investigated concreteness effects in words spelled in traditional Chinese script (currently used in Taiwan) for nouns and verbs. The authors reported robust concreteness effects regardless of task and word class. Nevertheless, task demand is also a potential factor influencing the topographic distribution of the concreteness effect reported in the previous studies. It has been demonstrated that the effect of concreteness is pronounced in frontal sites in studies that explicitly require imagery processing (West & Holcomb, 2000) and semantic judgment (Lee & Federmeier, 2008). On the other hand, studies that did not find significant concreteness effects in the frontal electrodes for verbs used an LDT task (Zhang et al., 2006). In addition to this, previous studies have also reported a larger negativity after 500 ms, called N700, in concrete than in abstract words in LDT (Barber, Otten, Kousta, & Vigliocco, 2013; Gullick, Mitra, & Coch, 2013; Huang, Lee, & Federmeier, 2010; Lee & Federmeier, 2008) suggesting that a complex mechanism may underlie the concreteness effect. Importance should be attached, therefore, to the various types of stimuli and task manipulations which have largely varied across previous studies and which have resulted in a less clear picture of the concreteness phenomenon.

2.4 MMN

The mismatch negativity (MMN) was first discovered by Näätänen and collaborators several decades ago (Näätänen et al., 1978). It is an ERP response elicited in oddball experiments by infrequent/deviant acoustic stimuli presented among frequent/standard sounds. It is extracted by subtracting ERP waves of deviant events from those of standard. The MMN is usually observed at frontocentral electrodes, peaking at about 100-250 ms from the onset of acoustic change regardless of whether subjects attend to or ignore stimuli. See Figure 2.1 for an illustration of the component. The underlying mechanism proposed is that the acoustic change activates short-term memory traces of the standard stimuli, or acoustic regularities (Winkler, 2007). This memory trace theory, however, is challenged by the fact that different presentation probabilities of deviant and standard stimuli unavoidably result in different degrees of habituation of neurons, which leads to N100 difference rather than a true MMN without N100 contamination (May & Tiitinen, 2010). However, even though N100 can temporally overlap with a true MMN, the MMN can still be very useful as a tool for neuroscience research, and new paradigms are being developed to reduce the effect of this confounding factor (Kujala et al., 2007).

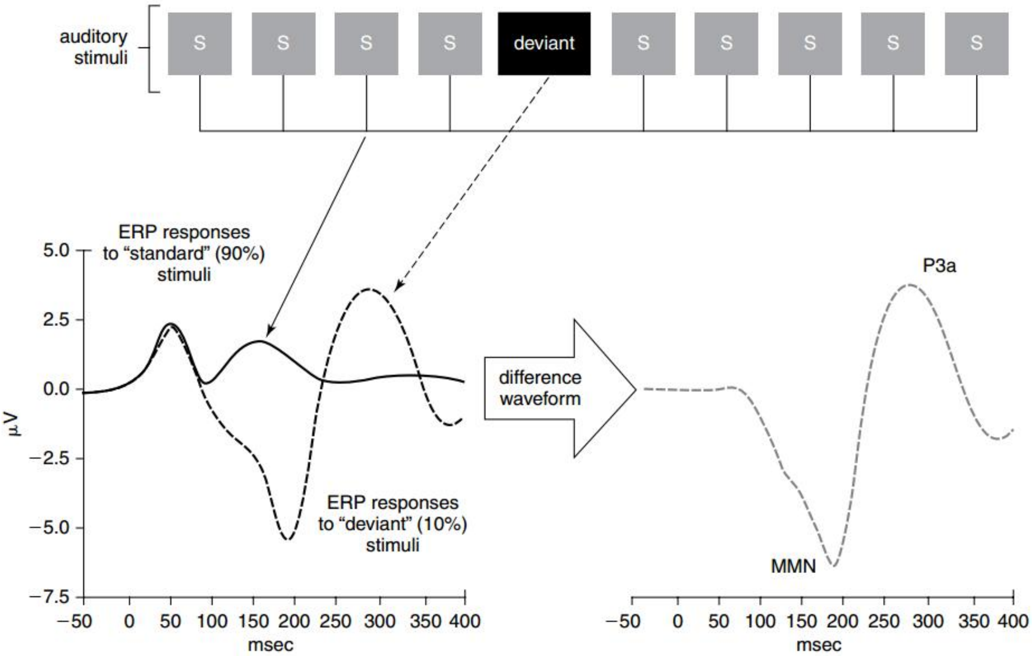


Figure 2.1 An example of MMN experimental design. ERP responses to standard (solid black line) and deviant (dashed black line) auditory stimuli, presented to participants, are compared. The resulting difference ERPs typically show the MMN (dashed grey line) with a peak around 200 ms. The negativity is plotted downward. Figure cited from Light et al. (2010).

MMN can be obtained in different paradigms. First and most typically, it can be elicited in an oddball paradigm where "deviant" sounds (presentation probability 10-20 %) occur within a stream of repetitive "standards" (presentation probability 80-90 %). It can be easily elicited by different types of stimuli at different levels of abstraction, from individual sounds to more complex auditory structures. One concern about the elicitation of this component, however, is about the large probability gap between standards and deviants. The neuronal populations responding to the standard stimuli could be more refractory than to the infrequent deviants, possibly resulting in overestimated MMN amplitudes (Jacobsen & Schröger, 2001). One solution is to include a control condition where the deviants are presented among several other deviants, sharing the same probability as the deviant in the oddball sequences (i.e., equi-probability paradigm). The refractoriness difference can then be partially eliminated by comparing the deviant in the oddball condition to the deviant in the control condition (Jacobsen, Horenkamp, & Schröger, 2003; Jacobsen & Schröger, 2001). The other solution is to swap deviants and standards in different blocks such that MMN can be obtained by subtracting the ERPs to standards in one block from those to the same stimuli presented as deviants in another block (i.e., deviant-standard-reverse/identity/same-stimulus paradigm). Jacobsen and Schröger (2003) compared the above two paradigms in investigating automatic change detection of acoustic durations and found that this reversed paradigm was a "sufficient" control in generating genuine MMN based on memory comparisons. Another paradigm is called the multi-feature optimum paradigm, developed by Näätänen, Pakarinen, Rinne, and Takegata (2004). These authors invented this new paradigm in which five types of acoustic changes (frequency, intensity, duration, perceived sound-source location and gap) are presented in the same sound sequence. This paradigm is based on the assumptions that the MMNs can be independently elicited for different auditory attributes and that the deviant tones can still strengthen the memory trace of the standard with respect to the stimulus attributes they have in common (i.e., repetitive standard stimuli will be compared with the previous stimuli). If the infrequent stimuli (deviant) do not match the memory trace of the standard stimuli, then the MMN will be elicited. In the multi-feature paradigm, the length of time of the experiment is significantly reduced, which can be a considerable advantage in experimental settings. Most importantly, no difference was found in the recording of MMNs using the new paradigm and those obtained in the traditional oddball paradigm (Näätänen et al., 2004).

In the linguistic domain, it has emerged from a number of studies involving auditory language processing that the MMN is sensitive to processing of languages at phonological (e.g., Dehaene-Lambertz, 1997), lexical (e.g., Sittiprapaporn, Chindaduangratn, Tervaniemi, & Khotchabhakdi, 2003; Alexandrov, Boricheva, Pulvermüller, & Shtyrov, 2011; semantic (e.g., Shtyrov, Hauk, & Pulvermüller, 2004) and syntactic (e.g., Hasting, Kotz, & Friederici, 2007) levels.

Specifically, auditorily presented real words have been shown to elicit enhanced MMN compared to acoustically and psycholinguistically matched pseudowords, in several different languages (e.g., Korpilahti, Krause, Holopainen, & Lang, 2001; Pulvermüller, Shtyrov, Kujala, & Näätänen, 2004; Sittiprapaporn et al., 2003; Gu et al., 2012; Gu, Zhang, Hu, & Zhao, 2013; Kujala et al., 2007) .The lexical enhanced MMN, often seen as peaking around 100-200 ms, is taken to suggest pre-attentive neural activation of existing cortical memory representations for real words. These representations are conceptualised as distributed and robustly interconnected neuron populations (Pulvermüller & Shtyrov, 2006). Based on this, the enhancement effect has been explained as a neural index of long-term cortical memory traces for real words, which enables activation of words even in the absence of attentional resources for verbal input (Pulvermüller, Kujala, et al., 2001). This theoretical position predicts that words of different frequency of occurrence may have memory traces which are different in strength. HF words could have superiority over LF words in the activation of the corresponding neural networks. Therefore, such a discrepancy should be reflected in the neurophysiological index of MMN, that is, HF words should have larger MMN amplitude relative to LF words. Indeed, this hypothesis has been tested in two recent studies using Finnish and Russian words (Alexandrov et al., 2011; Shtyrov, Kimppa, Pulvermüller, & Kujala, 2011). In comparison with the LF word, the HF word was found to elicit larger MMN in 140-200 ms time window (Alexandrov et al., 2011). The frequency effect on MMN amplitude, therefore, lends further support to the long-term memory trace theory.

Previous studies have also documented semantic access using an MMN approach. This line of research has mostly focused on how words from different semantic categories are cortically represented. Shtyrov et al. (2004) compared MMN responses to two English verbs involving different body parts, the hand-related verb *pick* and leg-related verb *kick* in an identity oddball paradigm. Neuronal distribution of hand-related "pick" was found to be more lateral while that of "kick" more focal. This topographical difference, confirmed by source analysis, seems to reflect different sensorimotor somatotopy rooted in the word semantics. In addition, recognition of the words started as early as 140-180 ms. These findings were replicated in an MEG study (Pulvermüller, Shtyrov, & Ilmoniemi, 2005). In this study, the neural responses of the magnetic counterpart of MMN, or MMNm to leg- and face/arm-related words (*potki*, kick and *hotki*, eat,) were compared to see their underlying spatiotemporal dynamics. It was found that the face-related word has more activation in inferior frontocentral areas than leg-related words and vice versa, at superior central areas between 140-200 ms after the unique identification point of the words. The different activation patterns clearly demonstrate early and automatic semantic access to spoken words.

In addition to semantics, MMN has also been used to investigate automatic syntactic processing. In one study (Pulvermüller & Shtyrov, 2003), short English subject-verb (pronoun plus verb: we come vs. we comes) sequences which were grammatically congruent or incongruent were contrasted as deviant and standard in a reverse non-attend oddball paradigm. In order to control for other acoustic differences between the critical verbs, a non-linguistic contextual condition (fn come/comes) was used. The "fn" referred to *filtered noise* stimulus which was a non-linguistic sound coined by filtering white noise reflecting the spectral features of the personal pronoun "we" (Pulvermüller & Shtyrov, 2003). MMN responses to the syntactically incorrect sentence were found to be larger than to the correct sentence, as early as 100-150 ms after the divergence point of the final utterance phoneme. Similar results of grammaticality-driven MMN/MMNm difference have been confirmed in other studies using different languages such as German (Hasting et al., 2007; Menning et al., 2005) and French (Hanna et al., 2013). Taken together, these studies show that syntactic violations can be detected very early under attention-deprived conditions.

In the ERP studies of language processing, the most commonly-studied event-related components are the ELAN, LAN, N400, and P600, as described above, so a natural question is: what are the advantages of the MMN as an appropriate tool for language study? The answer lies in its exclusive characteristics as described below (for reviews, see Pulvermüller & Shtyrov, 2006; Shtyrov & Pulvermüller, 2007). First, MMN indicates automaticity in detecting acoustic linguistic change. By automaticity, it is tentatively meant that language is processed without attentional effort. Behavioural and electrophysiological studies have already shown that automatic processing of linguistic information occurs at different levels of language. In the phonological processing field, studies show that phonological priming is significant even when prime words are invisible in a masked priming paradigm (Carreiras, Gillon-Dowens, Vergara, & Perea, 2009). Automatic lexical and semantic processing has also been demonstrated in other masked priming experiments (Diaz & Mccarthy, 2007). (Note here in a masked priming paradigm, participants are not aware of the masked prime but pay attention to target stimuli. So the "automaticity" conclusion in this line of study is slightly different from those, as shown below, which typically distracted participants' attention away from the stimuli of interest). By taking advantage of the high temporal resolution of the ERP technique, researchers have shown reliable semantic and syntactic effects (e.g., Batterink & Neville, 2013; Hahne & Friederici, 1999). However, most of these experiments require the participants' active attention to the input stimuli, so the evoked brain responses might be a combination of both attention and language-related correlates, rather than language response itself. MMN on the other hand can be easily generated even without participants' attention to the input stimuli (Tiitinen, May, Reinikainen, & Näätänen, 1994). It is therefore considered to reflect the brain's automatic discrimination of changes in the auditory sensory input. In this sense, it can be assumed to be a unique neurophysiological index of automatic processing of acoustic events (Näätänen et al., 2007). Additionally, in eliciting MMN, participants are normally carrying out a task that is irrelevant to language, for example, watching a silent film or playing a computer game when stimuli are presented. Second, MMN has a short latency between 80 and 250 ms, earlier than other language-related components such as LAN, N400, and P600. Though ELAN has a latency before 300 ms, it tends not to be reliably generated (Steinhauer & Drury, 2012). In the early time window before 250 ms, MMN has been documented to be sensitive to sound familiarity, lexical status, semantic properties and syntactic rules. The time window of MMN is also consistent with results of behavioural studies (Marslen-Wilson & Tyler, 1975; Sereno & Rayner, 2003). Therefore, the early latency of the component can help probe into early language comprehension processes. Furthermore, MMN can offer an opportunity to strictly control physical stimuli properties. Since MMN is computed by comparing responses to deviant and standard stimuli, the same acoustic contrast can be achieved in different experimental conditions while their linguistic features can be manipulated (See Shtyrov and Pulvermüller, 2007 for an example). In an identity oddball paradigm (detailed in Methodology part), the same linguistic stimulus can be used as a deviant in one oddball block and as a standard in a different control block. This way, true MMN can be obtained by minimising interferences from sensory confounds.

2.5 Visual MMN (vMMN)

After the discovery of MMN in the auditory domain, there was a hot debate as to whether there is an analogue in the visual modality. Recent research has, however, provided a convincing answer to this question. Czigler, Balazs, and Winkler (2002) first found the existence of vMMN in healthy subjects who viewed different colour gratings unrelated to the task at hand. This vMMN was manifested in a posterior negativity and anterior positivity between 120-160 ms post-stimulus. Since then, vMMN has been obtained for different visual stimulus features, such as colour (e.g., Berti, 2009; Czigler, Weisz, & Winkler, 2006), spatial frequency (e.g., Sulykos & Czigler, 2011), location (e.g., Berti & Schröger, 2006) and even complex stimuli such as facial emotions (e.g., Gayle, Gal, & Kieffaber, 2012) and abstract sequential regularities (e.g., Stefanics, Kimura, & Czigler, 2011). Generally, it is held that vMMN is an occipito-parietal negativity around 100 to 400 ms post-stimulus and it can be elicited by visual deviants violating some regularity established in the environment of standards.

Factors that affect vMMN in previous studies have included task relevance and the type of visual stimulus presented and, importantly, available attention. First, Czigler and Sulykos (2010) showed that task relevance can affect vMMN. In a set of healthy participants, reaction time was slower when the irrelevant background visual stimuli matched the relevant target-related change. The authors also observed a posterior negativity to deviant background stimuli themselves, but the vMMN was smaller in cases in which the task-relevant stimuli matched the irrelevant background stimuli. They suggested that the discrepancy between relevant and non-relevant background stimuli can be explained by participants learning that "not all deviants are significant" in cases where the task-relevant and irrelevant stimuli match. Second, the stimulus itself also affects the appearance of a vMMN. When deviant stimuli were embedded in a task-relevant stimulus stream (Berti, 2009), position deviants located in the upper visual field elicited a detectable visual MMN, but colour deviants and deviants presented in the lower visual field did not. This indicates that obtaining a reliable vMMN depends on both the location and nature of the stimulus. Type of stimulus may be particularly important to visual MMN due to the topography of the human visual system and its organisation into two distinct-but-interacting dorsal and ventral streams (Mishkin & Ungerleider, 1982). Third, attention is another critical factor that has an influence on vMMN. The availability of attention towards the stimuli is usually achieved in two ways: by manipulating the direction of attention to the stimuli or distraction task load/difficulty. Kuldkepp, Kreegipuu, Raidvee, Näätänen, and Allik (2013) investigated attentional effects on vMMN by manipulating attention either to the primary distraction task of motion onset detection ("Ignore" condition) or to an oddball sequence in the background ("Attend" condition). The authors found early (starting around 150 ms) and late (starting around 225 ms) stage vMMNs in parietal and occipital areas in the "Ignore" condition. In the "Attend" condition, however, the difference between deviants and standards was found only at a later interval. The authors attributed the absence of the early interval vMMN in the "Ignore" condition to the top-down visual attention suppressing the bottom-up change detection. Using a similar attention manipulation method, Kimura, Widmann, and Schröger (2010b) examined the role of attention in the representation of sequential regularity. A pattern of sequence (SSSSD) was implanted in an oddball paradigm, where deviant stimuli (D) and standard stimuli (S) differing in the dimension of visual luminance were presented. vMMN was found when participants paid attention to the luminance pattern but was absent when participants were discouraged from the stimuli or when they attended to the dimension of luminance itself (rather than the luminance pattern built with different stimuli which were displayed as a regular sequence). The authors concluded that for particular sequential regularity to be processed, attentional resources may be necessary. This result disagreed with the Kuldkepp et al. (2013) findings about the role of attention in the generation of vMMN. The difference might be due to the difficulty in representing the embedded regularities. While motion direction detection is quite noticeable and does not demand much attention in Kuldkepp et al. (2013), arguably, detecting and maintaining a relatively complex sequence regularity may require more support from attention and/or working memory in Kimura et al. (2010b). The other way of manipulating attention is to systematically change the difficulty of the primary distraction task, that is, the more demanding the distraction task, the less attention is involuntarily captured by the critical stimuli supposed to elicit vMMN. The same three levels of difficulty of the primary tasks were presented in Kimura and Takeda (2013) and Kremláček et al. (2013) to investigate attentional effects on vMMN. While Kremláček et al. (2013) did not find an effect of task difficulty in registering vMMN, the latencies of vMMNs increased with more difficult distraction tasks in Kimura and Takeda (2013) . The absence of vMMN modulation was attributed to insufficient saliency of the deviant/standard difference, so that the participants failed to notice the violations of regularity established through standards (Kremláček et al., 2013). Taken together, implicated in these studies is that top-down attention may interact with low-level stimuli attributes in updating context and generating predictions about expected stimuli.

Although vMMN is expressed as (multiple) negativities across a range of 100-400 ms, there has been some debate as to whether this negativity results from a visual refractory effect or a true detection of visual stimuli change. Similarly to MMN research in the auditory domain, because there is a large probability difference between standards and deviants, the habituation level of neuronal populations giving response to standards can be much higher than that of the afferent neuronal populations responding to the value of deviants. Therefore, the negativity in deviant-standard difference waves can be a mixture of both the vMMN elicited by deviant stimuli and the visual N100 difference between deviant and standard stimuli. One solution to this question is to turn to the different latencies of N100 and vMMN. Usually, vMMN has a latency outside of the latency range of 150-200 ms of the N100. However, it can be difficult to dissociate the two, since sometimes the latencies of the two components overlap. Kimura, Katayama, Ohira, and Schröger (2009) approached this question by combining the traditional oddball sequence (standard stimuli presentation probability 80% and deviant stimuli 20%) and the equi-probable sequence (all stimuli 20%). The equiprobable paradigm elicited two negativities, one bilateral around 100-150 ms, and the other right-dominant around

200-250 ms, while only the latter negativity was found in the oddball paradigm. This indicates that the early negativity is related to the refractory effect, while the later one is related to the memory component of stimulus change detection. In their study, Czigler et al. (2006) found two occipital/centro-parietal negativities in healthy adults viewing a set order of colour grids that was periodically displaced, with one negativity at 100-140 ms and the other 210-280 ms post-stimulus. The purpose of the set pattern of alternating colours was to determine if the visual MMN was related to a change in stimuli themselves or a detection of deviance from a pre-established pattern of change in stimuli. Only the negativity at 210-280 ms was elicited when the pattern of colour grids was violated, indicating that this later waveform reflects a comparison to an established stimulus pattern rather than the change in stimuli. Another way to reduce the confounding refractoriness effect is to adopt the identity paradigm as in the auditory MMN studies. This paradigm is often held to be useful in controlling physical differences between deviants and standards in the vMMN studies (Stefanics, Csukly, Komlósi, Czobor, & Czigler, 2012; Stefanics, Kremláček, et al., 2014). Since it has been found in the auditory MMN studies that the reverse block can provide a sufficient control of refractoriness effect (Jacobsen & Schröger, 2003), it can play a similar role in the visual modality because the refractoriness effect likely arises from different presentation probabilities which are modality-independent. In sum, there were several way of avoiding the refractoriness contamination on true vMMN. The identity paradigm can be a workable solution to the refractoriness effect and therefore has been adopted in quite a number of vMMN studies (Stefanics, Kremláček, et al., 2014).

While these studies are primarily linked with change detection in elementary visual objects and sequence regularities, only a handful of studies have attempted to reveal the sensitivity of vMMN in studies of higher-order language processing. For example, Wang and colleagues investigated the extraction of phonology in Chinese character reading (Wang, Liu, et al., 2013; Wang, Wu, et al., 2013). Mandarin Chinese is a tonal language, with four main meaning-bearing lexical tones embedded in the character pronunciation. In Wang, Liu, et al. (2013) homophone characters differing in orthography and semantics were visually presented in an oddball paradigm to participants who were asked to carry out a colour detection task. The sequence of homophones sharing a lexical tone (standards) was unpredictably violated by another string of homophones (deviants) with different tones, albeit with the same constant and vowel. The violation of lexical tone regularity produced strong vMMN as early as 140-200 ms, suggesting lexical phonology is processed early and automatically. A similar result was found in the other study with a similar paradigm but with the homophones presented outside of visual focus, thus adding to the evidence of phonological processing which is free from attentional focus (Wang, Wu, et al., 2013). Language-related effects at the level of phonological processing was also examined in another vMMN study (Files, Auer, & Bernstein, 2013). Visual speech stimuli (i.e., phonemes visually perceived through lip-reading) /ta/ and /fa/ were frequently shown to participants in two different streams. Occasionally, presentations of /ta/ and /fa/ were interspersed with the same deviant stimuli /zha/, which built a near and far articulatory moment contrast respectively. The near contrast gave rise to a vMMN over the right posterior-temporal area while the far contrast elicited a vMMN at bilateral sites. It was argued that the language related left hemisphere was sensitive to larger phonemic contrast while the right hemisphere was sensitive to fine-grained facial movement.

In another study, Shtyrov and colleagues (2013) carried out the first study identifying vMMN effects for words and word-like stimuli. They briefly presented five oddball blocks of Russian words and word-like stimuli parafoveally. In order to control for physical confounding, each of the five blocks shared the same deviant-standard orthographic contrast. Participants were asked to carry out a primary distraction task in the screen centre. It was reported that real words produced a larger brain response than pseudowords as early as 110 ms after stimulus onset. Both real word and pseudoword deviants were found to elicit vMMNs, at the 100-120 ms and 240-260 ms intervals. However, no interaction between the ERP responses to the stimulus type (standard vs. deviant) and lexical status (real vs. pseudoword) was found, suggesting that the vMMN might not be sensitive to lexicality change. This is not consistent with previous MMN studies in the auditory modality showing enhancement of the MMN of real words relative to pseudowords. Thus, more studies are needed to answer questions as to whether vMMN can be reliably elicited by linguistic stimuli, if so, at what levels of linguistic analysis the vMMNs are sensitive; and what is the influence of attentional modulation on this effect, among other questions.

A number of theories have been put forward to explain the underlying mechanisms of the vMMN. One account of the underlying process of vMMN is called the iconic memory mismatch account. Iconic memory is sensory-specific and plays an important role in the automatic encoding of a large amount of static visual sensory information. According to this notion, vMMN is considered to be elicited when a current deviant stimulus is incongruent with the iconic memory of the immediately-preceding standard stimulus. Although the iconic memory mismatch account can provide the simplest explanation for some research results, it fails to account for the need for repetition in eliciting the vMMN effect. Kimura, Katayama, and Murohashi (2006) used a stimulus sequence consisting of the random presentation of two equiprobable visual stimuli with different colours (A and B, 50% each). The authors found that vMMN was only elicited in response to a stimulus that was preceded by four repetitions of the other stimulus (e.g., OOOOX…), while the component could not be obtained in response to a stimulus preceded by one, two or three repetitions. This may suggest that in order to generate visual MMN, it is necessary to have some repetitive occurrences of visual stimuli. Thus, visual MMN is generated by a stimulus input incongruent with the sensory memory trace of a standard stimulus, formed by its repetitions (the sensory memory trace mismatch account). The prediction-error account, on the other hand, posits that the memory representation that encodes regularity operates as a prediction for the coming visual stimuli. When the stimuli in question violate the prediction of concrete visual events, vMMN can be obtained. Instead of a passive perceptual analyser of bottom-up perceptual information, this theory emphasises the active role of visual perception (Kremláček et al., 2016; Stefanics, Kremláček, et al., 2014). This theory has been claimed to be a unified explanation for the full range of relevant results (Kimura, 2012), though the theory is mainly based on non-linguistic vMMN studies. Still another theory postulates visual categorisation as the underlying basis for eliciting vMMN effects especially in studies involving complex stimulus features (Czigler, 2013). Human observers normally categorise visual objects fast and with apparent ease. Many studies have also shown that visual categorisation is an automatic cognitive process (Greene & Li, 2014; Li, VanRullen, Koch, & Perona, 2002; Thorpe, Fize, & Marlot, 1996). The vMMN effects derived from processing fairly complex characteristics ranging from perceptual symmetry (Kecskés-Kovács, Sulykos, & Czigler, 2013) and left/right hand (Stefanics & Czigler, 2012) to phonological information in print words (Wang, Wu, et al., 2013) are claimed to be a result of automatic visual categorisation (Czigler, 2013). That is, in an oddball paradigm, categorical information or abstract regularity are automatically extracted from the set of standards and facilitates comparison with the deviants, or members of the other category. The incongruence in categorising the incoming visual input will be reflected as a vMMN effect.

In sum, previous studies have found evidence of vMMN effects which can be elicited not only by low-level elementary visual features but by high-level written words. These findings indicate that vMMN can be a useful index of automatic change detection of visual information of various types.

2.6 Time-frequency analysis in language studies

While the "standard" ERP data analysis is to compute averaged evoked potentials (EPs) which are time-locked to an event of interest and compare across different experimental conditions the amplitudes (as well as latencies) as a function of time, an increasingly popular development in the analysis of electrophysiological language responses is to uncover their oscillatory neuronal dynamics in the frequency domain. Evoked activity features an identical phase ("phase-locked") and can be visible in averaging ERPs, whereas induced oscillations, though correlated with experimental conditions, have different onset times and/or phase jitter ("non-phase-locked"), and are therefore not visible in the time domain. Despite this, many studies have demonstrated that both evoked and induced activities are important modes of brain functioning (Roach & Mathalon, 2008). The sum of both evoked and induced event-related oscillations is called overall spectral power or event-related spectral perturbation (ERSP). Another important oscillatory concept is called the phase-locking factor/value (PLF/PLV) or inter-trial (phase) coherence (ITC/ITPC), which is an important complement to ERSP because it statistically assesses the event-related phase consistency of oscillations irrespective of their amplitude (Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1997). PLF value is between zero and one. If the phases during latency after the onset of a stimulus are a random distribution across trials, i.e., non-phase-locked activity, the value would be zero. If, however, the phases are identical across all trials, i.e., strictly phase-locked activity, the value would be one. In sum, time-frequency analyses of EEG signals provide additional information about which frequencies have the largest spectral power in a given latency and how their phases synchronise across time and space. These oscillatory dynamics have been found to be associated with various cognitive processes such as executive control, language and emotion. Therefore, a time-frequency analysis will at least add new insight to the traditional ERP approach (Bastiaansen, Mazaheri, & Jensen, 2012).

In the following is a brief review of previous studies on how Neural oscillatory activity are related to human cognition, especially language comprehension, before proceeding to recent work on the oscillatory correlates of auditory and visual MMN.

Neural oscillations are typically categorised into four frequency bands for analysis, delta (0–3 Hz), theta (4–7 Hz), alpha (8–12 Hz), beta (13–30 Hz, with the lower beta at 13-18 Hz), and gamma (above 30 Hz). A large corpus of studies over the last two decades has found a range of cognitive functions to be reflected in neuronal oscillatory dynamics in these four bands. Memory, as one of the integral parts of human cognition, is a critical ability by which information is encoded, stored and retrieved (Atkinson & Shiffrin, 1968). The primary function of working memory is to briefly maintain stimulus representation which is no longer present in a task at hand. Information in the long term memory system, on the other hand, is relatively stable and can be recalled automatically. Studies show that sustained gamma activity may play a critical role in holding working memory traces (Jokisch & Jensen, 2007; Kaiser, Ripper, Birbaumer, & Lutzenberger, 2003) and encoding of long-term memory representations (Osipova et al., 2006). In contrast, suppressing interference to prioritise task-relevant operations is correlated with an increase in the oscillatory activity in the posterior alpha band (Jensen, Gelfand, Kounios, & Lisman, 2002; Klimesch, Doppelmayr, Schwaiger, Auinger, & Winkler, 1999). This finding argues against the traditional idling rhythm hypothesis of alpha band that is typically found in subjects who relax and close their eyes (Pfurtscheller, Stancak, & Neuper, 1996). In addition, the theta frequency band has also been linked with memory retrieval and working memory (Bastiaansen, Oostenveld, Jensen, & Hagoort, 2008; Bastiaansen, Van Der Linden, Ter Keurs, Dijkstra, & Hagoort, 2005). Delta band activity is found to be involved in decision making and signal detection, to name but a few functions (Başar, Başar-Eroglu, Karakaş, & Schürmann, 2001; Yordanova, Falkenstein, Hohnsbein, & Kolev, 2004). Of particular relevance to the current project on visual word recognition are studies about the oscillatory correlates of lexical-semantic processing. Previous studies have found involvement of oscillatory activities in alpha band for semantic operations (Klimesch, 1999), and gamma band for semantic memory retrieval (Pulvermüller, 1999). Recent studies also seem to underscore the critical role of theta band oscillations in lexico-semantic processing. Bastiaansen et al. (2005) compared the oscillatory dynamics of meaning-bearing open-class words ("OC", e.g., nouns and verbs) and closed class words ("CC", e.g., determiners, articles) which carry more syntactic rather than semantic information, in a story-reading experiment. Both OC and CC words were found to have theta band power increase, as well as decrease in alpha and beta ranges. However, only OC words showed more theta synchronisation over left temporal areas, which is argued to function in lexico-semantic retrieval (Indefrey & Cutler, 2004). A follow-up study lends support to this viewpoint (Bastiaansen et al., 2008). In an LDT task, matched real words with meaning related to visually-perceived objects (e.g., words for "fruits", which can be seen with your eyes) and words related to auditory perception (e.g., words for "sounds", which are heard with your ears), as well as pseudowords and nonwords were presented to subjects." Similar to the previous findings of these authors, both types of real words featured a synchronisation increase in theta band and decrease in alpha and beta bands. Significant differences were found in comparing the commonly-induced theta bands. The “auditory” words induced larger theta band in the left auditory area than the left visual sites and vice-versa for the “visual” words. Since the “auditory” and “visual” words were matched in length and frequency, the theta band topographical contrast could best be explained in terms of their difference in semantic properties, i.e., foci of vision or audition. In addition, oscillatory studies on semantic and syntactic processing in various paradigms have also been reported (for a review, see Bastiaansen, Mazaheri, & Jensen, 2012). Difficulties in integrating world knowledge and semantic context into forming a coherent message can lead to a decrease in gamma band synchronisation. In contrast, a decrease in the lower beta frequency band (13-18 Hz) has been demonstrated to be involved in impeded syntactic processing due to syntactic violation or complexity (Bastiaansen, Magyari, & Hagoort, 2010).

While quite a number of studies have investigated oscillatory patterns in language comprehension as well as general cognitive processing, as seen in the above review, only a handful of such studies can be found in MMN research. Several time-frequency studies in auditory MMN have shown the important role of theta band in the generation of mismatch oscillatory responses (MOR). Fuentemilla, Marco-Pallarés, Münte, and Grau (2008) demonstrated theta power increase in the frontal regions of MMN but not in the temporal regions. Although a similar theta band increase was also shown in an MEG study (Hsiao & Cottrell, 2009), the authors reported the presence of theta oscillations in temporal rather than frontal areas. Another study, however, found theta band increase in both frontal and central regions (Ko et al., 2012). Together, these studies indicate a role of theta power in auditory change detection, although with varied spatial locations. Another frequency band, alpha band, has been evidenced in inhibitory functioning in the brain, and might reflect amplitude changes caused by unexpected deviants in an oddball paradigm. However, no difference in alpha band power between deviant and standard stimuli has been reported in the above auditory MMN studies. Recent studies in the visual modality, however, have indeed found such difference. Stothart and Kazanina (2013) and Tugin, Hernandez-Pavon, Ilmoniemi, and Nikulin (2016) both described stronger alpha power decease (or Event-Related Desynchronisation, ERD) induced by deviant than by standards. The authors related this to the distribution and flow of information between separated neurons. Tugin et al. (2016) also reported a larger increase of alpha band (or Event-Related Synchronisation, ERS) to deviant than standard items, despite an absence of vMMN in their study. In addition to alpha and theta bands, there are findings on the role of gamma band in MMN studies (for a review, see Herrmann, Rach, Vosskuhl, & Strüber, 2014), which is associated with both low-level physical encoding and high-level memory access.

It should be noted that very little time-frequency analysis has been attempted in language-related MMN studies. Given the confirmed roles of various frequency bands in linguistic processing as well as domain-general cognition, therefore, a time-frequency analysis of the ERP data of Experiment 5 will be carried out to paint a more complete picture of linguistic processing.

2.7 Chinese

The following is a brief introduction to Chinese characters, particularly the orthographic features and lexical tone system. There are basically two existing Chinese character systems, the "Simplified" Chinese script used in mainland China and the traditional Chinese script mostly used in Hong Kong, Taiwan and Macao. While the traditional script uses the same characters used before the 1950s, which have directly evolved from the ancient logographic origins of written Chinese, the simplified script has quite radically adapted these characters and uses a much smaller number of strokes or radicals (see below for a description). This simplified script was introduced to facilitate and extend literacy on the Chinese mainland (Xing, 2006). Although simplified in visual complexity, most of the simplified characters still display something of their origins of formation and maintain the spatial features of the traditional ones. All the characters mentioned in the thesis hereafter refer to the simplified characters.

In Chinese, each character corresponds to a morpho-syllable. Hanyu Pinyin ("Han Language Spelling Sound") is the official Romanisation transcription system in mainland China for standard Chinese (Standard Mandarin), which uses English letters to represent Chinese phonemes. However, this does not mean there is a one-to-one correspondence between a pinyin transcription and a character, and homophones are extensively found in the language and are differentiated by lexical tone, which is not normally reflected in pinyin transcription. In Mandarin Chinese, there are four basic lexical tone patterns, which are the high level tone (also known as 1st tone), the high rising tone (2nd tone), the fall-and-rise tone (3rd tone) and the high falling tone (4th tone). In addition, a neutral tone (0 tone or light tone) is used on particles, to suggest tonal change as a result of neighbouring syllable(s). To take the pinyin transcription "yi" for example, this can correspond to as many as 60 different characters according to the Xinhua Zidian dictionary (Editorial-Board, 2005). When applied with a high level tone, yi1, it can denote characters such as 一 (*one*). With a high rising tone (yi2), it corresponds to characters such as 已 (*has done something*), among others. With a fall-and-rise tone (yi3), it can be one of another group of characters, including, for example, 宜 (*agreeable*). When used with a high rising tone (yi4), it could refer to 亿 (*100 million*) or many other characters. So homophones in Chinese, although represented by the same pinyin transcription, differ hugely in meaning and orthographic form (characters). Next, the focus will be on the Chinese orthography.

The fundamental building unit of a Chinese character is called a stroke, which is defined as a single continuous writing movement before a writer lifts his/her pen from the writing surface (See Figure 2.2 for various examples of character strokes and Table ***2.1*** for a detailed explanation of each stroke) (Tseng, Chang, & Chen, 1965). Strokes of various shapes are assembled to form relatively more complex components (radicals) which can stand alone or can combine to form characters. However, how the strokes are ordered and organised is not random and the strokes of a character are configured according to general rules and spaced appropriately inside an imaginary square.

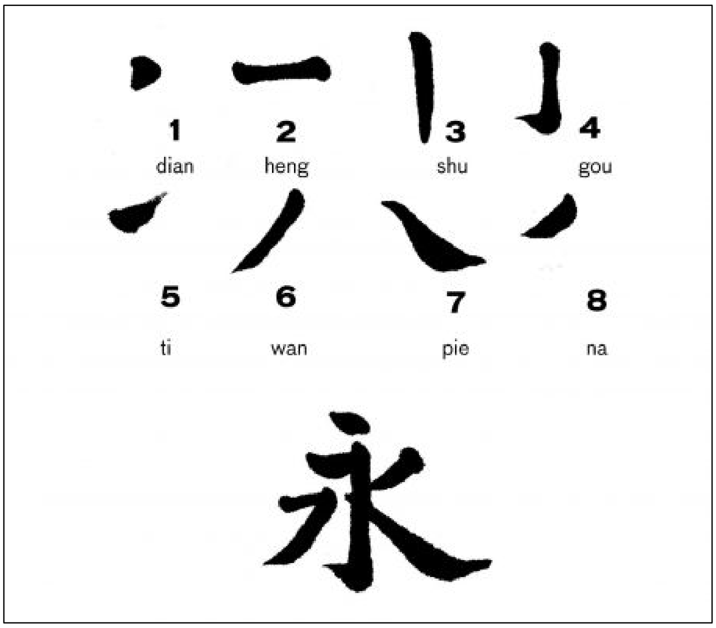


Figure 2.2 The eight basic writing strokes as illustrated in the Chinese character "yong" (meaning "forever"). From "Chinese character Yong," n.d., from http://education.asianart.org/explore-resources/background-information/introduction-chinese-character-and-brush-strokes

Table 2.1 An English translation of the stroke names

Order	Stroke name	English translation
	dian	Tiny dash
2	heng	Rightward stroke
3	shu	Downward stroke
4	gou	A stroke suddenly orienting to left. It does not stand alone but usually appends to the other ones.
5	ti	Raising up and rightward
6	wan	Long falling and tapering curve
7	pie	Short falling leftwards
8	na	Falling downward right

As mentioned above, strokes are normally grouped to form a stroke set or component, which is loosely termed a "radical". Radicals serve as the building blocks of a character. Functionally, this term here includes both "semantic" and "phonetic" radicals, respectively referring to the type of information they provide about the character which the radical is part of. Thus, as a general rule, semantic and phonetic radicals give cues to the meaning and pronunciation of a character respectively (Feldman & Siok, 1999; Taft & Zhu, 1997). For example, the semantic radical 钅 of the character 钢 (/gang1/, steel), means *metal*, which is relevant to the character's meaning, while its phonetic radical 冈 is pronounced /gang1/, thus carrying the same pronunciation as the host character. One caveat here is that the relationship of radicals to characters is not always a transparent or direct one. The phonetic radical, for example, is less "reliable" in that it often only provides a rough cue to the host character's pronunciation. Phonetic regularity means the extent to which a host character's pronunciation can be derived from the way the phonetic part of the host character is pronounced. It is negatively correlated with lexical decision latency (Liu, Shu, & Li, 2007). Therefore, phonetic regularity can be an important factor in selecting appropriate stimuli in psycholinguistic experiments.

In terms of spatial configuration, characters which are made up of radicals can be analysed into different structures, depending on analysis criteria. For convenience purposes, in this study the focus is on the four most common types of character structure, which covers a majority of characters in Chinese: *integral, left-right, top-bottom and enclosure* (including the half and full enclosure subtypes). An integral character is made up of one radical component which cannot be decomposed further at the radical level (e.g., 人, /ren3/, *people*). The remaining four types are called compound characters in that all of them are built with more than one radical combined together. Compound characters account for more than 70 %

of all characters. One important characteristic of these characters is the functional role of the radical positions. In other words, the predefined positional information of the radicals has functional relevance for the character's meaning and pronunciation. Conventionally in left-right characters, a semantic radical is located on the left and a phonetic radical on the right, as seen in the above example of 钢. For vertical top-bottom structured characters, the upper part normally is the semantic radical while the lower part the phonetic radical. Take "草" (/cao3/, *grass*) for example. The semantic radical "艹" is at the top of the host character and means "grass". The lower part "早" (zao3), gives a clue (in this case a rough indication) to the pronunciation of the host character. Taken together, radical identity and radical position are the two most important features of Chinese character recognition (Tsang & Chen, 2009). Swapping radical positions, without changing componential radical identities, can change a character's lexical status. To continue with 钢 for example, a reversal of the left-hand semantic radical and right-hand phonetic radical of this character violates the positional regularity rule, resulting in a non-character which is totally unacceptable to a Chinese reader. However, replacing the semantic radical 钅 with 牜 ("animal") can produce a pseudo-character 㸾. In this case, the positional rule is abided by, since the new radical 牜 is also a meaning-bearing component placed correctly on the left. However, this change of radical also results in an odd (non-existing) pairing of the new semantic and old phonetic radicals. In Chinese character dictionaries there is no such compound character, so this is a pseudo-character. Taken together, by manipulating positional regularity and radical identity, a single set of phonetic and semantic radicals can be employed to build real, pseudo- and non-characters. Since, normally, radicals are fixed in size, these different types of characters occupy the same space and have identical visual complexity. Thus, Chinese orthographic patterns can be manipulated to control for physical variance between lexical stimuli of different types, which is important in this type of psycholinguistic experiments.

2.8 Summary

With this chapter, a general background to the thesis project and a review of key concepts and relevant literature has been presented. Among the ERP components possibly relevant to this study, vMMN, as an index of automatic processing of visual information, has been discussed as a useful tool in investigating early and automatic language dynamics.

Chapter Three: Methodology

This chapter presents the general methods used in the five experiments reported in this thesis. First, the experimental design and the specific identity paradigm to elicit vMMN in the experiments are described. Second, a general introduction of participant profile, stimuli selection, experimental procedure, EEG data recording and ERP data analysis is given. Methodological information specific to respective experiments will be indicated later in the methods section of each experiment report.

3.1 Experimental design and paradigm

This project aimed to investigate how Chinese single-character words are processed, especially at early latencies, and whether they can be processed automatically. A series of five experiments were conducted to achieve this aim. Experiments 1-4 targeted early and automatic processing at the lexical level while Experiment 5 dealt with semantic processing. The last experiment was designed to test whether the findings in the Chinese language could be generalised to a different non-ideographic script, that is, Spanish.

As stated in Chapter 1, an MMN design recently developed in the visual processing field was adapted to the current language research context. From several specific paradigms for vMMN elicitation (Stefanics, Kremláček, et al., 2014), an identity (also termed same-stimulus or deviant-standard-reverse) paradigm was adopted in the current study. In this paradigm, a control condition was added, where the role of standard and deviant stimuli in the traditional block is reversed. vMMN is then computed by comparing the identical stimuli acting as deviants and standards across different blocks. There are three reasons for this choice of paradigm:

First, the identity paradigm is held to reduce the physical differences which are a potential confounding factor in vMMN elicitation. In traditional MMN studies, normally the MMN component was derived by subtracting the ERPs to standards, from those to deviants in the same block (Stefanics, Kremláček, et al., 2014). However, this practice may confound MMN effects, due to the possible physical differences between deviants and standards. This is particularly the case given the variability of stroke combinations in Chinese character structure. In contrast to this design, the identity MMN paradigm has been found to be a suitable way to control for physical difference and has been adopted in both auditory (e.g., Endrass, Mohr, & Pulvermüller, 2004) and visual MMN studies (e.g., Stefanics et al., 2012). Therefore, the identity MMN paradigm was used in the current study.

Second, the identity paradigm may help mitigate the so-called refractoriness effect. This refers to when the different presentation probabilities characterising the traditional oddball paradigm may lead to different degrees of habituation of the neural activity patterns. Specifically, the higher rate of repetition of standards relative to deviants will result in a higher degree of refractory effect in neural activity patterns specialised for the standard, thus yielding reduced exogenous components such as the N100 and P100. In contrast, the less frequent presentations of deviants can produce larger obligatory components (Pulvermüller & Shtyrov, 2006). As a consequence, a direct comparison of deviant and standard stimuli, as carried out in the standard oddball paradigm, may run the risk of a mis-estimated MMN, involving the exogenous effect difference induced by standards and deviants (Kujala et al., 2007; Schröger & Wolff, 1996). To acquire genuine MMN based on memory trace comparison, therefore, an equal probability control was introduced in later MMN studies, to tackle the refractoriness effect (Jacobsen & Schröger, 2003; Schröger & Wolff, 1996). In this protocol, several different stimuli are arranged in a block without a particular standard stimulus (i.e., the equal probability blocked control). Jacobsen and Schröger (2003) compared the auditory duration MMNs elicited by the equal probability protocol and the identity oddball paradigm. They demonstrated that the results were "equivalent" and the reverse block was a sufficient control, although the deviant-standard-reverse paradigm does not control for the refractoriness effect directly. While this reverse paradigm originates from the auditory domain, it can be applied to the visual domain too because the refractoriness effect resulting from the presentation rate gap between deviants and standards should occur without much difference in either auditory or visual presentation mode (Qiao et al., 2015; Yang et al., 2016).

Third, small controlled cohort of stimulus tokens can be accommodated in the identity paradigm. Although stimulus variance has been attributed as a main factor for the absence of transient and short-lived early language effects (Pulvermüller & Shtyrov, 2006), massive, and therefore unnatural repetitions, especially of a single token of linguistic stimulus, may lead to an exaggerated MMN due to the refractoriness effect. In contrast, a reasonable number of tokens can introduce more variability in basic visual features where different neuronal populations are stimulated, and so have the advantage of reducing stimulus-relevant refractoriness effect (May & Tiitinen, 2010). This practice can also prevent local adaptation which might lead to deviant-related effects (Stefanics et al., 2012). Participants need to abstract shared features from the low-level visuo-orthographic variety and represent the feature in a stable way. However, the advantage of multiple stimulus identities may not be easily achieved using the traditional direct deviant-standard comparison paradigm. As shown in Shtyrov et al. (2013), the critical deviant-standard contrast (/K/ vs. /H/ in Russian) must be shared in different lexicality contexts. This limitation arguably prevents it from accommodating more tokens for either deviants or standards.

3.2 Stimuli

The critical stimuli were selected with strict matching between control variables so that the variable under investigation could be solely manipulated. Five tokens of each stimulus type were provided. In selecting the final stimuli, a norming study on a seven-point Likert scale was carried out to validate the choice of stimuli (except in the case of Experiment 6 using Spanish materials and radical-based symbols). Participants were asked to do a non-linguistic colour tracking task, except in the case of Experiment 3 where participants were instructed to directly monitor deviant changes.

3.3 Procedures

Each trial started with a fixation cross displayed for 500 ms in the centre of a grey screen background. This was followed by two copies of a character stimulus (Size: 75×75 pixels; font: Sinsum; colour: black) presented perifoveally to the right and to the left of the cross. The distance from the centre of each character to the fixation centre was 7.2 degrees horizontally. The cross and characters remained on the screen for 150 ms, followed by an inter-stimulus interval of 600 ms where the black cross occasionally and unpredictably changed. This was followed by the presentation of another character stimulus, with the same configurations as the previous one. Then a blank screen with a random duration of 200 to 300 ms concluded one trial. In order to maintain participants' attention to the screen centre and not to the perifoveally presented characters, fixation crosses, black or red or green, were always displayed in the middle of the screen. During the experiment, participants were seated in a comfortable chair at a viewing distance of 50 cm. For an example of this procedure, see Figure 4.1 in p.67.

Depending on experimental aims, participants' primary tasks changed, which are specified in each experiment in the Chapter Four.

3.4 Data recording

Due to the six experiments being carried out in three different laboratories (State Key Laboratory of Cognitive Neuroscience and Learning in Beijing Normal University, Cognitive Neuroscience of Language Lab in University of Nottingham Ningbo China, and Psycholinguistics Lab in University of La Laguna, Spain), two different EEG recording systems were used in the project: a Synamps amplifier (Compumedics NeuroScan, El Paso, TX) with a 32-channel 10-20 system electrode cap (QuickCap, Neuromedical Supplies, VA, USA) was used for Experiment 1, and a BrainAmp DC amplifier and Brain Vision Recorder (Brain Products, Germany) was used in the rest of the experiments. However, the recording configurations such as sampling rate, band pass filter, electrode impedance, reference electrode choice, were kept the same.

3.5 Data processing

All the data were processed offline using Brain Vision Analyzer version 2.1.1.327 (Brain Products, Munich, Germany), following a procedure of bandpass filtering, ocular artifact reject, segmentation and averaging according to specific experimental conditions.

3.6 Data analysis

The effect of stimulus type on ERPs was analysed using repeated measures Analysis of Variance (ANOVA) of Type (standard and deviant) by Condition (e.g., real and pseudo-characters in Experiment 1) by Topographical factor(s). Both midline and lateral analyses were carried out. All the statistics were performed using R software (http://www.rproject.org). In reporting results, the original degrees of freedom were kept and p values were corrected for sphericity violations using the Greenhouse-Geisser epsilon. Bonferroni correction for multiple comparisons were used throughout the experiments.

Chapter Four: Experiments

This chapter is composed of a series of six experiments designed to answer the questions presented in Chapter 1. Experiment 1 explores whether the previously-documented lexical auditory MMN can be replicated in a visual modality by comparing mismatch responses (MMR) to well-matched, Chinese real and pseudo-characters in an identity oddball paradigm involving non-character fillers. As the size of stimulus change is shown to affect MMN elicitation in previous studies, Experiment 2 investigates how a reduced magnitude of deviance may influence visual MMR, by directly contrasting real and pseudo-characters, instead of comparing real-/pseudo- characters with non-characters (as in Experiment 1). Experiment 3 investigates how attention may influence vMMN elicitation in lexical processing. Experiment 4 deals with the influence of lexical frequency on vMMN effects. While all four experiments focus on automatic processing at the orthographic level of character form, Experiment 5 moves to the semantic level of character meaning and examines whether differential processing of concrete and abstract characters is reflected in vMMN effects. Finally, Experiment 6 explores whether the vMMN effects found in the Chinese language in Experiment 1 can be replicated in Spanish, an alphabetic language.

4.1 Experiment 1: Lexical vMMN in Chinese: An exploration

The first experiment aims to explore whether meaningful real characters and pseudo-characters elicit vMMN and if so, to examine the differences between them. Previous auditory MMN studies have shown early and automatic encoding of lexicality information as indexed by a larger MMN effect for real words compared to matched pseudo-words (for a review, see Pulvermüller & Shtyrov, 2006). The lexical MMN enhancement of real words has been attributed to their robust underlying long-term memory representations (Pulvermüller, Kujala, et al., 2001). In contrast, pseudo-words elicit weakened or no MMN, due to the fact that they have no corresponding lexical entries and so no lexical activation, especially in a non-attend condition. Since the word representations supported by neurobiologically-structured neural networks are assumed to be modality-independent, that is, functioning equally for auditory word stimuli and visual word stimuli, theoretically, the automatic activation of auditory memory representations that has been previously documented can be expected to occur in other modalities, such as vision. Visually presented real words will therefore predictably elicit enhanced vMMN compared with pseudo-words. This prediction is tested in Experiment 1 using Chinese characters and well-matched pseudo-characters. In addition, a control group of non-Chinese participants was recruited. These participants, although living temporarily in China, have very limited knowledge of Chinese characters. The predicted enhanced vMMN for real characters in the native group is therefore not expected in the non-native readers, where memory traces for Chinese characters will not have been established, due to their limited learning experience with this type of linguistic stimuli.

4.1.1 Materials and methods

Participants

Twenty-four native speakers of Chinese and 19 other language speakers who were neurologically healthy, with normal or corrected-to-normal vision, volunteered to take part in the experiment. They were all right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). The research protocol was approved by the Research Ethics Committee of the State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, China and the Research Ethics Committee of the University of Nottingham Ningbo, China.

All participants provided their informed written consent before taking part in the experiment. All of them attended a post-experiment interview session, providing their feedback about their experience of the experiment. Based on the interview as well as on the EEG data, four Chinese participants had to be rejected due to their occasional active attention to character stimuli, or due to excessive artifacts or incomplete experiment. All the remaining 20 Chinese participants reported no awareness of the regularity of oddball presentation of the to-be-ignored character stimuli. The final sample of this native group, therefore, included 20 participants (aged 22.6 ± 2.2 years; 7 males). For the non-native group, data from two people were rejected due to eye discomfort or report of active attention to the linguistic stimuli. This resulted in a sample of 17 participants (aged 26.5 ± 7.8, 7 males). All of these participants had lived in China for at least 6 months but reported limited experience of the Chinese written language. Ten of them had 60-120 hours of classroom learning of

Chinese in the past three years while the other seven had no formal training in the language.

Stimuli

Three types of character stimuli, real, pseudo- and non- characters with five exemplars of each were prepared (See Table ***4.1*** for all the stimuli). Importantly, in order to reduce physical differences between them, the same semantic and phonetic radicals were used across the three types of stimuli. Real characters used in the experiment are existing Chinese characters, with an average frequency of 83.80 per million and an average length of 8.3 strokes, according to the Chinese Single-character Word Database (SCWD, www.personal.psu.edu/pul8/psylin-norm/psychnorms.html, Liu, Shu & Li, 2007). Pseudo-characters were built by exchanging the semantic and phonetic radicals of real characters while maintaining their conventional radical positions. The Xinhua Zidian (*Xinhua Character Dictionary*) (Editorial Board, 2005) confirmed that the pseudo-characters were non-existent. Five non-characters were also invented by reversing the positions of semantic and phonetic radicals of real characters. These non-characters were used as fillers in the experiment.

Table 4.1 Three different types of stimuli

Stimuli	**1**	**2**	**3**	**4**	**5**
Real character	物	钢	结	神	饭
(Pinyin)	wu4	gang1	jie2	shen2	fan4
(Gloss)	*stuff*	*steel*	*knot*	*god*	*meal*
Pseudo-character	⿰纟勿	⿰牜冈	⿰钅吉	⿰饣申	⿰衤反
Non-character	⿰勿牜	⿰冈钅	⿰吉纟	⿰申礻	⿰反饣

As explained above, using the same radicals in the three types of characters enabled maximal similarity in terms of visuo-orthographic analysis. Despite the physical feature similarity, the different pairings of radicals resulted in real, pseudo- and non- characters respectively. The lexical status difference was further validated by a lexical status norming test administered to participants after the EEG recording. The task of participants was to judge to what extent the character presented was a meaningful real character on a seven-point Likert scale (7 = most likely to be a real character). ANOVA was used to test rating differences between the three lexical conditions. For the native group, between-condition differences were significant [$F(2, 57) = 213.74$, $p < 0.001$, $M_{\text{real character}}$: 7.00, $M_{\text{pseudo-character}}$: 4.16, $M_{\text{non-character}}$: 1.05]. Post-hoc test indicated that the three stimulus conditions were significantly different from each other in lexicality rating ($ps < 0.001$). For the non-native group, between-condition difference also reached significance, [$F(2, 48) = 6.92$, $p < 0.01$, $M_{\text{real character}}$: 5.08, $M_{\text{pseudo-character}}$: 4.82, $M_{\text{non-character}}$: 3.68]. Multiple comparisons, however, revealed no difference between real and pseudo- characters ($p > 0.05$), though both of them were rated more real-character-like than non-characters ($ps < 0.05$). This result confirmed that the non-native participants had limited knowledge of Chinese characters.

Four oddball blocks were built and run randomly. They included: block 1, standard non-character vs. deviant pseudo-character (sNdP); block 2, standard pseudo-character vs. deviant non-character (sPdN); block 3, standard non-character vs. deviant real character (sNdR), and block 4, standard real character vs. deviant non-character (sRdN). In each block, standards and deviants were presented with the restriction of no identical stimulus type or stimulus identity appearing sequentially and no fewer than two standards between any consecutive deviants. Each of the four blocks was initiated by three standards. Altogether in one block, 540 standards and 90 deviants were presented, evenly represented by five exemplars of each character type.

Procedure

As shown in Figure 4.1, each trial started with a fixation cross displayed for 500 ms in the centre of a grey screen background, followed by two copies of a character (Size: 75×75 pixels; font: Sinsum; colour: black) presented perifoveally both to the right and to the left of the cross. The distance from the centre of each copy of the character to the fixation centre was 7.2 degrees horizontally. The cross and characters remained on the screen for 150 ms, followed by an inter-stimulus interval of 600 ms where the black cross changed to red occasionally and unpredictably. This was followed by another presentation of a character, with the same configurations as the previous one. Then a blank screen with a random duration of 200 to 300 ms concluded one trial. In order to maintain participants' attention to screen centre and not to perifoveal characters, fixation crosses, black or red, were always displayed in the middle of the screen. During the experiment, participants were seated in a comfortable chair at a viewing distance of 50 cm. They were instructed to focus their attention on detecting the red crosses in the centre of the screen, by pressing the "D" key on the keyboard as quickly and accurately as possible. Response time and accuracy were recorded by E-prime version 2.0 (Psychology Software Tools Inc., USA) and analysed. In addition, they were asked to mentally count how many times they saw a red cross and report it in each break session. This way, we could maintain a relatively stringent control of attention away from the lexical stimuli. After the experiment, participants were asked to join in a post-experiment session (see above).

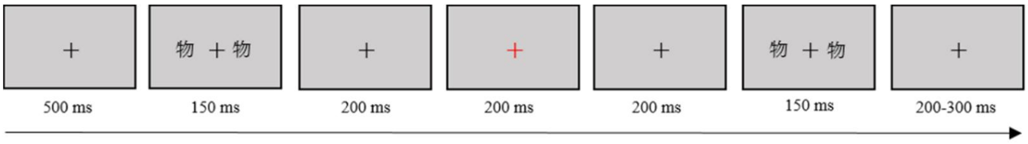


Figure 4.1 Illustration of the experimental procedure. Participants were asked to detect fixation colour change as accurately and quickly as possible and to memorise how many times they saw a red fixation cross in a block.

Data recording and analysis

Two EEG recording systems were used in the current study. For the native group, EEG was registered using a Synamps amplifier (Compumedics NeuroScan, El Paso, TX, USA) with a 32-channel 10-20 system electrode cap (Figure 4.2A; QuickCap, Neuromedical Supplies, VA, USA) and a sampling rate of 500 Hz and a band-pass from 0.05-100 Hz. All electrodes were referenced to the tip of the nose. The horizontal and vertical electrooculograms (EOGs) were monitored by electrodes placed at the outer canthus of each eye and those above and below the left eye respectively. All impedances were maintained at or below 5 kΩ. Offline, the data were analysed in Brain Vision Analyzer. First, they were digitally bandpass-filtered between 0.1-30 Hz (24 dB/Octave) using a finite impulse response (FIR) filter (Butterworth zero phase filter). Ocular artifacts were corrected using an algorithm (Gratton, Coles, & Donchin, 1983). Continuous data with signal amplitudes surpassing an absolute value of 100 µV were excluded. Finally, the data were segmented from -150 to 600 ms relative to the onset of stimuli with a 150 ms pre-stimulus baseline. For the non-native group, Brain Vision Recorder with a 32-channel EasyCap (Figure 4.2B; Brain Products, Germany) was used but with the parameters set the same as the

NeuroScan system. Brain Vision Analyzer was used for data processing with the same analysis parameters and procedure as the native group.

The segments of standards and deviants of real and pseudo-characters were averaged for further analysis. In averaging, 1) the first 3 trials in each block, 2) trials where participants gave a response, and 3) the ones where there were cross colour changes, were excluded. As a result, the mean number of accepted segments for final analysis was 368 (standard derivation: 42), 82 (11), 357 (52) and 81 (9) for natives and 406 (63), 81 (10), 412 (69), 80 (8) for non-natives, corresponding to standard and deviant pseudo-characters, and standard and deviant real characters, respectively. See Figure 4.3 for deviant and standard ERPs of the two groups.

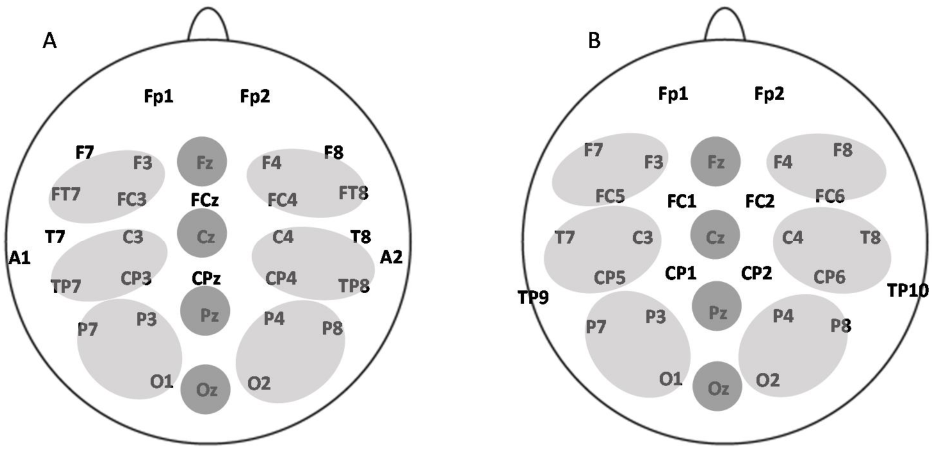


Figure 4.2 The two electrode caps and scalp regions. (A): the cap used in the native group; (B): the cap used in the non-native group. The clusters in dark grey were lateral regions while those in light grey were middle areas in ANOVAs. Note the clustering of electrodes is similar between the two experiments.

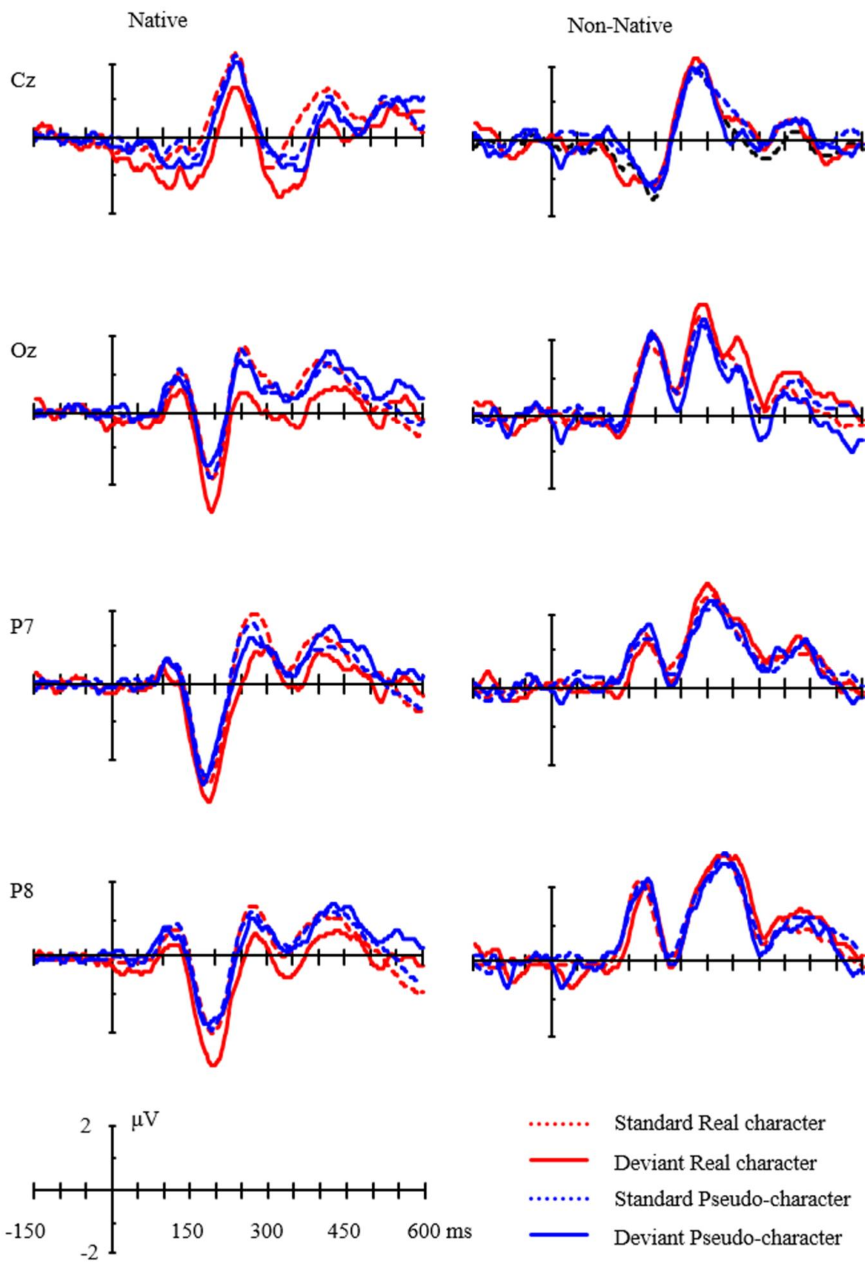


Figure 4.3 Comparison of deviant and standard stimulus ERPs of real and pseudo-characters. Left: ERP waveforms for deviant (red solid) and standard (red dotted) real character conditions and for deviant (blue solid) and standard (blue dotted) pseudo-character conditions at midline electrodes Cz, Oz, P7 and P8, in the native group. Right: ERPs of deviant and standard character stimuli for the non-native group. Negativity is plotted downward.

Difference deflections were derived by subtracting the ERPs to standards from those to deviants within the same character condition, for real and pseudo-characters respectively (Figure 4.4). For natives, the topographical maps of the deviant-minus-standard difference waveforms suggested that negativity was distributed differently for real and pseudo- characters (Figure 4.5). Generally, real character negativities were focused in the central-parietal area, while the difference negativities for pseudo-characters were relatively weak, with a distribution mostly in the frontal area. For the non-native group, reduced negativity appeared (Figure 4.5 Right).

Three intervals of 120-160 ms, 160-200 ms and 330-370 ms were chosen for analysis with reference to previous linguistic vMMN studies (Shtyrov et al., 2013; Wang, Liu, et al., 2013). The effect of stimulus type on ERPs was analysed using repeated measures ANOVA of Type (standard and deviant) by Lexicality (real and pseudo-character) by Region. Both midline and lateral analyses were carried out. For the native group, in the midline analysis, the topographical factor Region included frontal (Fz), central (Cz), parietal (Pz) and occipital (Oz) electrode sites. In the lateral analysis, the topographical factors were Region: frontal (F3/4, FC3/4, FT7/8), central (C3/4, CP3/4, TP7/8) and parietal (P3/4, P7/8, O1/2), and Hemisphere (left and right). The same statistical analysis was carried out for the non-native group, albeit with slightly different electrodes due to the different cap used in the Brain Vision system. Specifically, in the lateral analysis, Region was defined as frontal (F3/4, FC5/6, F7/8), central (C3/4, CP5/6, T7/8) and parietal (P3/4, P7/8, O1/2) areas. In the midline analysis, the same electrodes as in the native group were chosen. See Figure 4.2 for an illustration of clustering of electrodes.

In the native Chinese group, for the standards and deviants of both real and pseudo- characters, N170 was observed at parietal-occipital electrode sites (Figure 4.3). In order to explore the lateralisation of this component, amplitude measurements were submitted to an ANOVA of Lexicality (real and pseudo-characters) by Hemisphere (left: O1, P3, P7 and right: O2, P4, P8). The ERPs of the non-native group, however, did not show any N170-like ERP deflection. In all the above analyses, where appropriate, critical values were adjusted using the Greenhouse-Geisser correction for violation of the assumption of sphericity.

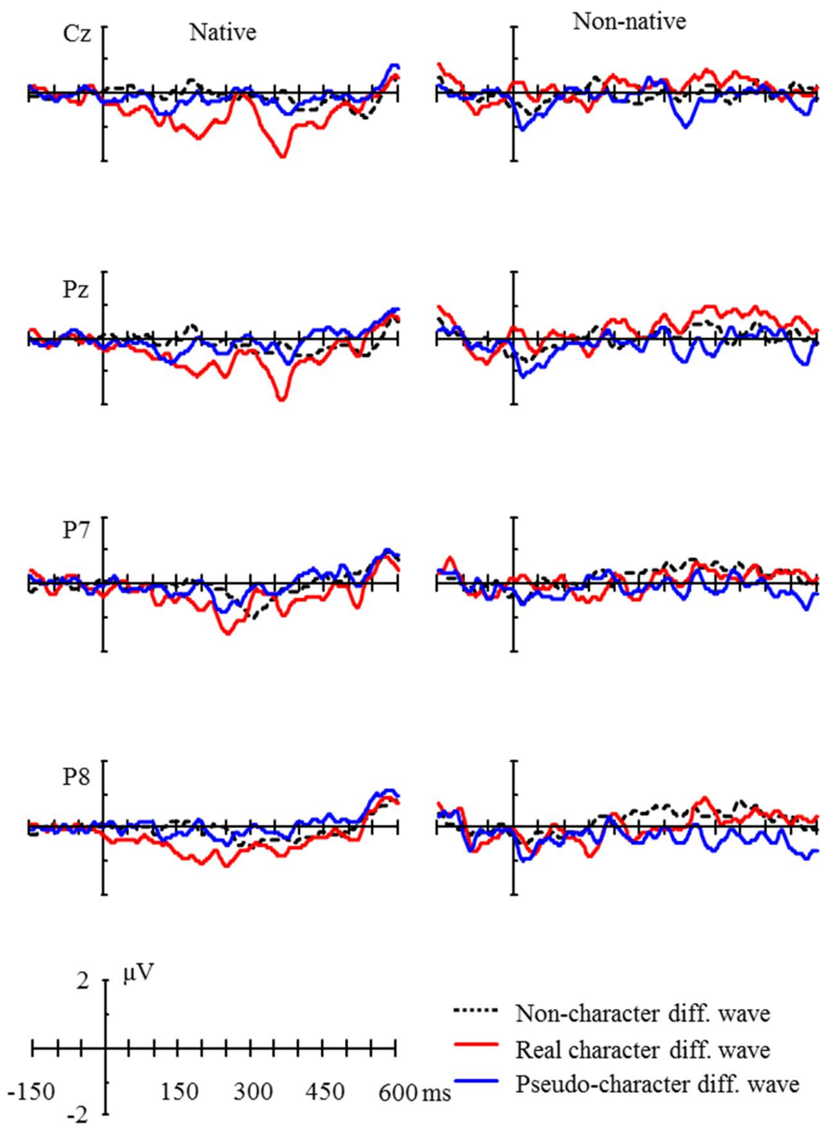


Figure 4.4 The real- and pseudo- character deviant-minus-standard difference ERPs. Deviant-minus-standard difference waves of real characters (Red solid), pseudo-characters (Blue solid) and non-characters (Black dotted) at midline electrodes Cz, Oz, P7 and P8 for native (Left) and non-native (Right) group. Negativity is plotted downward.

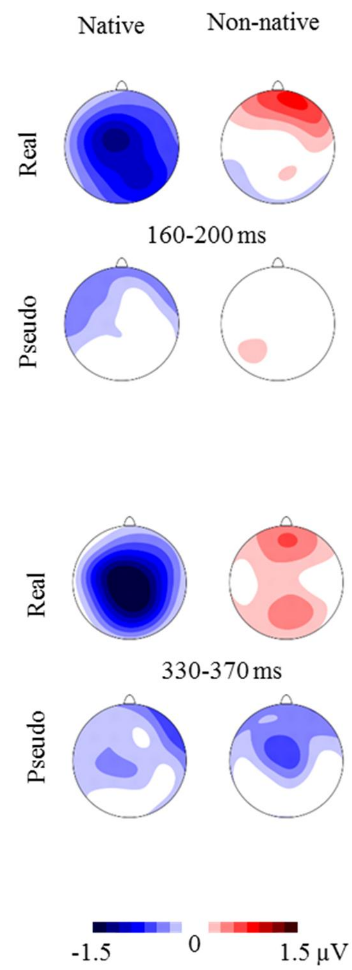


Figure 4.5 The topographical maps of the difference ERPs. The maps of real and pseudo- character conditions in the native (Left) and non-native (Right) groups in the time window of 160-200 ms (upper part) and 330-370 ms (lower part). Plotted in the lower part is the topography for real and pseudo-character conditions of the two groups in the interval of 330-370 ms.

4.1.2 Results

Behavioural results

Table 4.2 shows the behavioural results for both native and non-native groups. The repeated measures ANOVAs of Group (native vs. non-native) by Block (four blocks) did not yield significant differences in reaction time (ms) and accuracy rate (%) between blocks and between the two groups (ps > 0.05).

ERP results

<u>Native group</u>

Table 4.2 Behavioural results (standard deviation in parenthesis)

	sRdN		sNdR		sNdP		sPdN	
	Native	Non-native	Native	Non-native	Native	Non-native	Native	Non-native
Reaction time	441.1 (62.6)	474.3 (59.4)	455.0 (69.3)	482.3 (55.2)	444.7 (50.1)	475.0 (46.6)	448.6 (56.6)	473.3 (46.5)
Accuracy rate (%)	98.4 (3.6)	98.7 (2.4)	98.0 (5.0)	98.9 (1.9)	97.1 (5.5)	98.6 (1.8)	97.0 (2.6)	98.4 (2.1)

N170. ANOVA yielded a main effect of Hemisphere [F(1, 19) = 4.91, $p < 0.05$, partial $\eta^2 = 0.23$], which was due to more negative N170 response in the left (-2.01 μV) than in the right (-1.57 μV). The interaction between Hemisphere and Lexicality did not reach significance ($p > 0.1$), suggesting that real characters and pseudo-characters elicited similar N170 amplitude in the two hemispheres.

120-160 ms. ANOVA revealed main effects of Type in midline and in lateral analyses [$F_{(1, 19)} = 10.68$, $p < 0.01$, partial $\eta^2 = 0.36$; $F_{(1, 19)} = 14.03$, $p < 0.01$, partial $\eta^2 = 0.42$], resulting from more negativity to deviants than standards [-0.43 vs. 0.08 μV; -0.62 vs. -0.12 μV]. The interaction between Type and Lexicality was not observed in either midline or lateral analyses (*p*s > 0.1).

160-200 ms. In midline electrodes, ANOVA yielded a reliable main effect of Type, [$F_{(1, 19)} = 8.57$, $p < 0.01$, partial $\eta^2 = 0.32$] and an interaction between Type and Lexicality [$F_{(1, 19)} = 5.39$, $p < 0.05$, partial $\eta^2 = 0.22$]. Post hoc analysis indicated that, while for real characters, deviants were more negative than standards (-1.14 vs. -0.20 μV, $p < 0.001$), for pseudo-characters, no such difference was revealed ($p > 0.1$). At lateral sites, ANOVA showed a main effect of Type [$F_{(1, 19)} = 9.74$, $p < 0.01$, partial $\eta^2 = 0.34$] and its interaction with

Lexicality [$F_{(1, 19)} = 4.22$, $p = 0.054$, partial $\eta^2 = 0.18$]. Post hoc analysis revealed a significant difference between deviant and standard for real characters (-1.64 vs. -0.83 μV, $p < 0.01$) but no such difference for pseudo-characters ($p > 0.1$). There was also a main effect of Hemisphere [$F_{(1, 19)} = 8.66$, $p < 0.01$, partial $\eta^2 = 0.31$], with a more negative response in the left than the right hemisphere (-1.35 vs. -0.92 μV).

330-370 ms. In midline electrodes, ANOVA showed a reliable main effect of Type [$F_{(1, 19)} = 18.97$, $p < 0.001$, partial $\eta^2 = 0.50$] and an interaction between Type and Lexicality [$F_{(1, 19)} = 6.80$, $p < 0.05$, partial $\eta^2 = 0.26$]. Post hoc analysis revealed significant difference between deviants and standards only for real characters (-0.85 vs. 0.45 μV, $p < 0.001$). In lateral sites, ANOVA indicated a main effect of Type [$F_{(1, 19)} = 17.10$, $p < 0.001$, partial $\eta^2 = 0.47$]. The interaction between Type and Lexicality reached marginal significance ([$F_{(1, 19)} = 4.00$, $p = 0.06$, partial $\eta^2 = 0.17$]. Post hoc analysis revealed significant difference between deviants and standards for real characters (-0.64 vs. 0.36 μV, $p < 0.001$), but not for pseudo-characters (-0.29 vs. 0.08 μV, $p > 0.1$).

<u>Non-native group</u>

120-160 ms. ANOVAs yielded an interaction of Type and Region in midline analysis [$F_{(3, 48)} = 5.59$, $p < 0.01$, partial $\eta^2 = 0.26$] and an interaction of Type, Region and Hemisphere in lateral analysis [$F_{(2, 32)} = 6.69$, $p < 0.05$, partial $\eta^2 = 0.29$]. Further analysis, however, failed to show a significant difference between deviants and standards (*p*s > 0.1) in either midline or lateral analyses.

160-200 ms. There were no significant effects in this time window (ps > 0.1).

330-370 ms In the midline electrodes, ANOVA yielded a marginally significant interaction of Type and Region ($p = 0.08$). Post hoc analysis, however, did not reveal a difference between deviants and standards, either for real or pseudo-characters (*p*s > 0.1). In the lateral sites, there were no significant effects (*p*s > 0.1).

4.1.3 Discussion

This experiment explored whether written Chinese lexical information is extracted automatically and rapidly. ERPs to the same type of orthographic stimuli presented as deviants and standards across experimental blocks were compared in an identity paradigm. For the native group, first, an N170 component was shown in the parietal-occipital area. Second, both real and pseudo-characters elicited similar vMMNs in the 120-160 ms window. In the intervals of 160-200 ms and 330-370 ms, however, only real characters elicited vMMN. In the control group of non-Chinese readers, there was no evidence of N170 in the parietal-occipital area and no evidence of vMMN observed in the midline and lateral analyses. In the following, the results will be discussed in detail.

N170 at parietal-occipital sites

The present study found that within the first 200 ms after the linguistic stimulus onset, N170 was elicited over parietal-occipital areas and left-lateralised in the native group. This result agrees with previous studies indicating that this component reflects expertise in written word processing (Bentin et al., 1999; Lin et al., 2011). Interestingly in the current study, this component was readily elicited even when participants' attention was directed away from the visual stimuli. As described earlier, similar results have also been found in recent studies of Chinese in attention-deprived contexts (Wang, Liu, et al., 2013; Wang, Wu, et al., 2013), although no N170 effects were observed in a recent vMMN study of Russian (Shtyrov et al., 2013). One tentative explanation for this discrepancy is the different presentation parameters used in the studies. In Shtyrov et al.'s study, orthographic stimuli were presented only for 100 ms, shorter than the 150 ms adopted in our study and the 200 ms in Wang, Liu, et al. (2013) and Wang, Wu, et al. (2013). As indicated by Shtyrov et al. (2013), this tachistoscopic way of presentation, together with their distraction task of large color circle detection in the middle, may have affected viewers' perceptual discrimination of the otherwise familiar orthography. The delicate difference between deviants and standards lied only in the single ending letters of three-letter short sequence might also contribute to difficulty in orthographic processing in Shtyrov et al. (2013).

Lexical vMMN effect

This experiment is among the few that have successfully investigated vMMN effects in the language area. By comparing deviants and standards of real and pseudo-characters in Chinese, evidence of vMMNs elicited by lexical stimuli was found for native readers of Chinese. This finding extends previous vMMN studies in non-linguistic areas such as bar orientation (Kimura et al., 2009), colour (Clifford, Holmes, Davies, & Franklin, 2010; Czigler et al., 2002; Thierry, Athanasopoulos, Wiggett, Dering, & Kuipers, 2009) and facial emotion (Kimura, Kondo, Ohira, & Schroger, 2011; Stefanics et al., 2012; Zhao & Li, 2006), into the field of language. It also replicates the finding of Shtyrov and colleagues (2013) using Russian words and pseudowords, indicating that words and word-like stimuli can indeed elicit vMMN effects. The early onset of the vMMN effect in the current study, about 120 ms, is also consistent with recent language-related vMMN studies (Shtyrov et al., 2013; Wang, Liu, et al., 2013; Wang, Wu, et al., 2013) as well as studies investigating non-linguistic visual features (for a review, see Stefanics, Kremláček, et al., 2014).

The lexical vMMN effect in the current experiment was obtained with careful consideration to avoid potential confounding factors. First, it is important to ensure that the refractoriness effect inherent in visual oddball paradigm is controlled for. The current study attempted to overcome this habituation effect by adopting the identity oddball paradigm which has been demonstrated to be an appropriate control condition (Jacobsen & Schröger, 2003) although it should be noted that this approach cannot eliminate completely the refractoriness effect arising from the different presentation probabilities of stimuli. In addition, five tokens for each stimulus condition were accommodated in this study, instead of the single token per stimulus type often used in previous auditory MMN studies. Multiple tokens can introduce more variability in basic visual features where different neuronal populations are stimulated and so have the advantage of reducing the stimulus-relevant refractoriness effect (May & Tiitinen, 2010). This practice can also prevent local adaptation effects contributing to deviance-related effects (Stefanics et al., 2012). Second, it is necessary to minimise any physical differences which may confound vMMN effects. In the current study, based on the orthographic regularity of Chinese characters, care was taken to build real and pseudo- characters which were matched in overall visuo-orthographic attributes. Specifically, exactly the same radical identities were used to build real and pseudo-characters. Moreover, the radical positional information, a unique characteristic of Chinese characters, also remained unchanged. Only the pairings of semantic and phonetic radicals in real characters were changed to create pseudo-characters. This way, the lexical status (real vs. pseudo- character) was manipulated at a minimum price of physical change. Comparisons were thus drawn between physically well-matched deviants and standards of real and pseudo-characters. Therefore, possible confounding factors of physical feature difference can be reasonably eliminated in explaining the lexical vMMN effect. Third, a non-linguistic distraction task in the foveal area was implemented to avoid attention to the vMMN-eliciting stimuli in the periphery. This is important, as attention can affect potential vMMN effects (Stefanics, Kremláček, et al., 2014).

Real and pseudo-character mismatch responses: a comparison

To the best of the author's knowledge, this is the first time that a lexicality effect on vMMN elicitation has been observed for written language processing. This effect cannot be attributed to physical differences between the stimuli. As argued above, the real and pseudo- characters were matched on overall orthographic similarity, using the same set of semantic and phonetic radicals. In addition, they shared a context where five tokens of non-characters were used as fillers. Therefore, there were no differences in terms of contextual influence. A further control of physical difference was the measurement of the vMMN by comparing the ERPs to the same character type acting as deviants and standards (i.e., real word vMMN = ERPs to real character deviants vs. real character standards).

In the initial stage (before 160 ms) of vMMN elicitation, both real and pseudo- characters yielded similar results. This may be attributed to the similar visual configurations of the two stimulus types. Real and pseudo- characters share radical identities and legal radical positions, in contrast to non-characters which have illegal positions of radicals. This perceptual feature common to real and pseudo-characters was rapidly captured and reflected neurophysiologically as vMMNs of indistinguishable amplitude. In order to find whether the positional legality was decoded in this window, real and pseudo- character were collapsed as legal characters in comparison with non- characters in terms of their difference ERPs. Separate ANOVAs of position Legality (legal vs. non-character) and Region (as described above) were carried out for midline and lateral sites. ANOVA yielded a main effect of Legality, showing that Legal characters elicited larger vMMN than non-characters (-0.56 vs. -0.03; -0.53 vs. 0.04 μV), both in midline and lateral analyses ([$F_{(1, 19)} = 4.46$, $p < 0.05$, partial $\eta^2 = 0.19$; $F_{(1, 19)} = 6.75$, $p < 0.05$, partial $\eta^2 = 0.26$]). That the radical position decoding occurred early also agrees well with previous studies in Chinese (Yum, Su, & Law, 2015) and in English (Hauk, Patterson, et al., 2006). For example, in an explicit character detection task in Yum, Su, et al. (2015), non-characters (described as “illegal pseudo-characters” in their study) were discriminated from legal pseudo-characters around 100 ms, as indexed by a larger P100 at left posterior electrodes. Together, the current data suggests that radical position is represented mentally and accessed at the initial stage of character recognition. In contrast to Yum, Law, et al. (2015) where active attention was directed to the critical stimuli, in the current experiment, this early positional representation was detected even when participants’ attention was distracted away from the critical stimuli by a non-linguistic task. This automatic detection of radical position can be attributed to the participants’ internalised knowledge of the character structure, presumably an integral part of the character representations. This may explain why detection of such delicate spatial configurations can occur very rapidly even in an unattended condition for Chinese natives. However, knowledge of the positional legality in Chinese characters, unlike elements of visual objects such as object shape and orientation, needs to be acquired in active language learning. Long-time language exposure and/or practice may be a prerequisite for mastery of Chinese radical spatial regularities and automatic processing of these. The absence of vMMN on the part of the non-native group lends support to this view, although they did show some knowledge of character structure at a behavioural level, as they rated both real and pseudo- characters significantly more real-character-like than non- characters.

As discussed above, earlier decoding of radical positions discriminates between real and pseudo-characters on the one hand, and illegal/non-characters on the other. This early coarse orthographic analysis informs the following more fine-grained processing at the compound-character level. This is reflected in the presence of vMMN for real characters but an absence for pseudo-characters in the interval of 160-200 ms. The locus of the real character vMMN advantage over pseudo-characters may lie in the integration of the sublexical radicals of the character stimulus. According to the part-based character encoding model (Ding, Peng, & Taft, 2004), in reading Chinese, the initial phase of stroke-based feature detection and radical processing feeds forward to the intermediate stage of integration of left and right radicals, which distinguishes between real and pseudo- characters. Since the correct pairing of the two types of radicals (real characters) can correspond with their established memory representations, which are supported by robust underlying neural interconnections, successful activation of their lexical entries occurs. The visual input of the incorrectly bound radicals (pseudo-characters) will be left without further activation due to a lack of corresponding representations. On the other hand, as components in real characters are combined in a conventionalised fashion, developing knowledge of their specialised radical pairing and character forms demands extensive language experience of various forms, such as rote memory and writing, which are common learning practice in Chinese literacy education. Support for this argument is the absence of vMMN at this stage of processing for the non-native participants. In fact, discrimination between real and pseudo-characters poses a bigger challenge than that of real/pseudo characters versus non-characters, because it requires the knowledge of not only the basic sublexical structure, but more importantly, the knowledge of the unique combination of specific radicals. With limited Chinese learning experience, it is, therefore, difficult for the non-Chinese readers to tell apart the two types of characters, as evidenced by the null difference between the two in the rating task (See above in section on stimuli). Their behavioural performance and the corresponding physiological absence of vMMN effects in real and pseudo-characters further support the long-term memory trace theory of language (v)MMN elicitation (Pulvermüller & Shtyrov, 2006; Shtyrov & Pulvermüller, 2007).

It is interesting to note that different from auditory lexical MMN studies, where pseudo-words also elicit MMNs, albeit with a reduced amplitude (Pulvermüller & Shtyrov, 2006; Shtyrov & Pulvermüller, 2007), no vMMN was found for pseudo-characters in native readers in the current experiment, either in the early (160-200 ms) or late (330-370 ms) intervals. This difference may be related to the stimulus presentation modalities. In the auditory mode, with the acoustic and phonological information unfolding over time, the competing representations of lexical neighbours of both real and pseudo-words may be activated before the real word is finally identified (Marslen-Wilson, 1987). Thus the partial activations of pseudo-words may lead to reduced MMN. In contrast, in a visual domain such as in the current experiment, real and pseudo- characters are presented as they are in entirety and immediately, leaving less opportunity to activate representations of relevant neighbours of pseudo-characters, especially given the short stimulus duration in a non-attend design. As a result, activation of pseudo-characters may be minimal, and thus no reliable sign of vMMN appears.

The dissociation of real and pseudo- characters in vMMN elicitation is in concordance with previous studies in the auditory modality which consistently show enlarged MMN effects elicited by real words in comparison with pseudowords, in different languages such as Finnish (Korpilahti, Krause, Holopainen, & Lang, 2001; Pulvermüller, Kujala, et al., 2001), English (Shtyrov & Pulvermüller, 2002), Thai (Sittiprapaporn et al., 2003) and German (Endrass et al., 2004). In terms of the time course of the effects, the present data shows that real characters yielded vMMN before 200 ms. This finding agrees well with previous lexical MMN investigations. For example, in an auditory MMN study by Pulvermüller and collaborators (2001), MMN amplitude produced by a syllable completing a real word was larger than that a pseudoword at 150 ms after the stimulus uniqueness point. Endrass and colleagues (2004) used a similar reverse oddball condition to control for acoustic differences in their study. They found that German words elicited enhanced MMN relative to matched pseudowords within the first 200 ms. It was claimed by these authors that the pre-existing neuronal memory traces of real words are activated in an automatic manner and that the enhanced MMN component is a neurophysiological correlate of such activation (Pulvermüller & Shtyrov, 2006). Through associative language learning experience over time, the neuronal network, represented as memory traces, becomes sufficiently robust to bolster rapid and automatic response to real words even in an attention-deprived condition (Shtyrov & Pulvermüller, 2007). Consistent with previous auditory MMN investigations, the current results lend support to this proposal and extend its applicability to the visual modality. The presence of vMMN for real characters also indicates that the component can be used as an index for higher-order language processing as well as for elementary visual feature processing.

It should be noted that the lexical vMMN effect latency around 160-200 ms appeared later than some recent studies reporting an effect within 100 ms (Shtyrov & Lenzen, 2017; Shtyrov & MacGregor, 2016). These studies, however, deviated from a direct comparison of vMMN/difference ERPs to real and pseudo- words but rather, focused on comparing all real and pseudowords regardless of their presentation probabilities, i.e., being deviants or standards. Using this method, for example, Shtyrov and Lenzen (2017) even reported a much earlier latency of 30 ms for larger response to real and pseudowords. Therefore, the different statistical analyses might be held at least partially responsible for such the latency difference between my result and theirs. Another possible reason might lie in the number of tokens used in each stimulus condition. In Shtyrov et al. (2013), only one token was used for each condition in comparison to five tokens in my experiment. The higher number of tokens in each condition presumably could mean more difficulty for the cognitive system to abstract a pattern/regularity from the repetition of standards. Consequently, this might affect the time needed to automatically process lexicality changes.

Following the early window of 160-200 ms, enhanced vMMN is sustained in a later time window of 330-370 ms. This later effect is distributed in central-parietal areas, which closely resembles that of the earlier window of 160-200 ms (See Figure 4.5 Left). The topographical similarity may imply overlapping lexical (-semantic) processing in the two intervals. Therefore, it is presumed that a secondary lexical reanalysis may occur in this interval. This later effect is also consistent with previous auditory findings (Pulvermüller & Shtyrov, 2006) supporting the presence of the early and late MMNs in automatic lexical processing. In clarifying the difference between them, some studies have shown that the MMN in the later windows is subject to attentional modulation such that with attentional resources, pseudo-word MMN is increased to the extent that it has similar or larger amplitude than real word MMN, in contrast to real word behaviour, found to be relatively immune to attentional variation (Garagnani, Shtyrov, & Pulvermüller, 2009; Shtyrov, Kujala, & Pulvermüller, 2010). Whether the interaction between auditory MMN and attention works similarly for the visual modality remains unknown and will be explored later in the current dissertation.

4.1.4 Conclusion

In sum, Experiment 1 investigated how lexical information in Chinese is automatically and rapidly extracted, by exploring whether the previously-documented auditory linguistic MMN effect could be replicated in a visual modality. ERPs to perifoveally-presented quintuplets of real- and pseudo-

Chinese characters were registered in an identity MMN paradigm, while participants were distracted by a non-linguistic task. In native Chinese readers, real characters elicited early and late vMMN effects whereas pseudo-characters showed no evidence of vMMN. In the non-native Chinese participants, however, there was no sign of vMMN for either real or pseudo-characters. The current findings, in line with previous findings on pre-attentive automatic lexical processing in the auditory domain, suggest that the underlying memory representations for real characters may drive automatic lexical processing of visually-presented stimuli even in an unattended condition.

4.2 Experiment 2: Contrasting real and pseudo- characters in one block

In Experiment 1, both real and pseudo- characters were contrasted with non-characters. The relatively large physical difference, or magnitude of stimulus change, between real/pseudo- and non- characters, may have facilitated the automatic deviance detection and thus vMMN elicitation. In the auditory domain, MMN can be elicited by “a discriminable change in any repetitive aspect of auditory stimulation” (Näätänen et al., 2007), with a larger deviance leading to a higher MMN amplitude and shorter latency (Kujala et al., 2007; Näätänen et al., 2007). In the visual modality, however, inconsistent findings have been reported. Maekawa et al. (2005) manipulated the number of vanes in windmill patterns used as stimuli (standard, deviant and target) in order to vary deviance. The magnitude did not modulate vMMN amplitudes but latencies. Czigler and Sulykos (2010) compared different stimulus orientations in eliciting vMMNs. The vMMNs to 30º and 60º deviancies from orientations were not significantly different. In contrast, in a study directly investigating the effect of degree of deviance on vMMN elicitation, Czigler et al. (2002) found vMMN to color changes in a large deviance condition (red-green oddball blocks) but no vMMN in a small deviance condition (red-pink oddball blocks), suggesting deviance may affect vMMN. Since all these studies used elementary visual features to examine deviance effects, it remains unknown whether deviance changes in the special category of orthography has a role in the elicitation of vMMN.

Against this background, Experiment 2 aims to investigate whether the presence or absence of vMMN might be influenced by the magnitude of stimulus change between deviant and standard stimuli. In this experiment, real and pseudo-characters were therefore contrasted directly with each other as deviants and standards, in contrast to the previous experiment, where both real and pseudo-characters were contrasted with non-characters as deviants and standards. It is important to point out again that though the same set of semantic and phonetic radicals was used in real, pseudo- and non- characters, radicals in real and pseudo- characters were legal in their positions while those in non-characters were illegal. Therefore, while in Experiment 1, there existed a contrast of radical position legality, no such a contrast could be found in Experiment 2, leading to a relatively smaller size of deviancy magnitude. Thus the magnitude of deviance between real and pseudo- characters was not as large as that between real/pseudo- characters and non-characters. It is therefore predictable that a weakened or no vMMN could be elicited by the two types of linguistic stimuli. This hypothesis was tested in the current experiment.

4.2.1 Materials and methods

Participants

A group of twelve college students (mean age 19.8, 6 males) took part in the experiment for course credit. They were right-handed and had normal or corrected-to-normal vision. All of them reported no neurological or psychological illnesses. They gave their informed written consent before the experiment. The study was approved by the Research Ethics Committee of the University of Nottingham Ningbo, China.

Stimuli

The critical stimuli were the same as in Experiment 1. Real characters acted as standard stimuli and pseudo-characters as deviant stimuli in one block and vice versa in the other block.

Procedure

The experimental procedure was the same as in Experiment 1.

Data recording and analysis

Data were recorded and analysed as in Experiment 1, with the same recording system as that used in the non-native group. The grand-averaged ERPs and their difference waveforms and maps (Figure 4.6 and Figure 4.7) did not show obvious negativity. With reference to Experiment 1 and the current data, intervals of 160-200 ms and 330-370 ms were selected.

4.2.2 Results

Behavioural results

No differences between the two blocks were found for either reaction times or accuracy rates ($ps > 0.05$).

ERP results

Below is the grand-averaged ERPs of the four conditions of standard and deviant real characters, and standard and deviant pseudo-characters, in the electrodes of Cz, Oz, P7, P8 (Figure 4.6), as well as their corresponding difference ERPs and topographical maps (Figure 4.7). No clear negativity is evident.

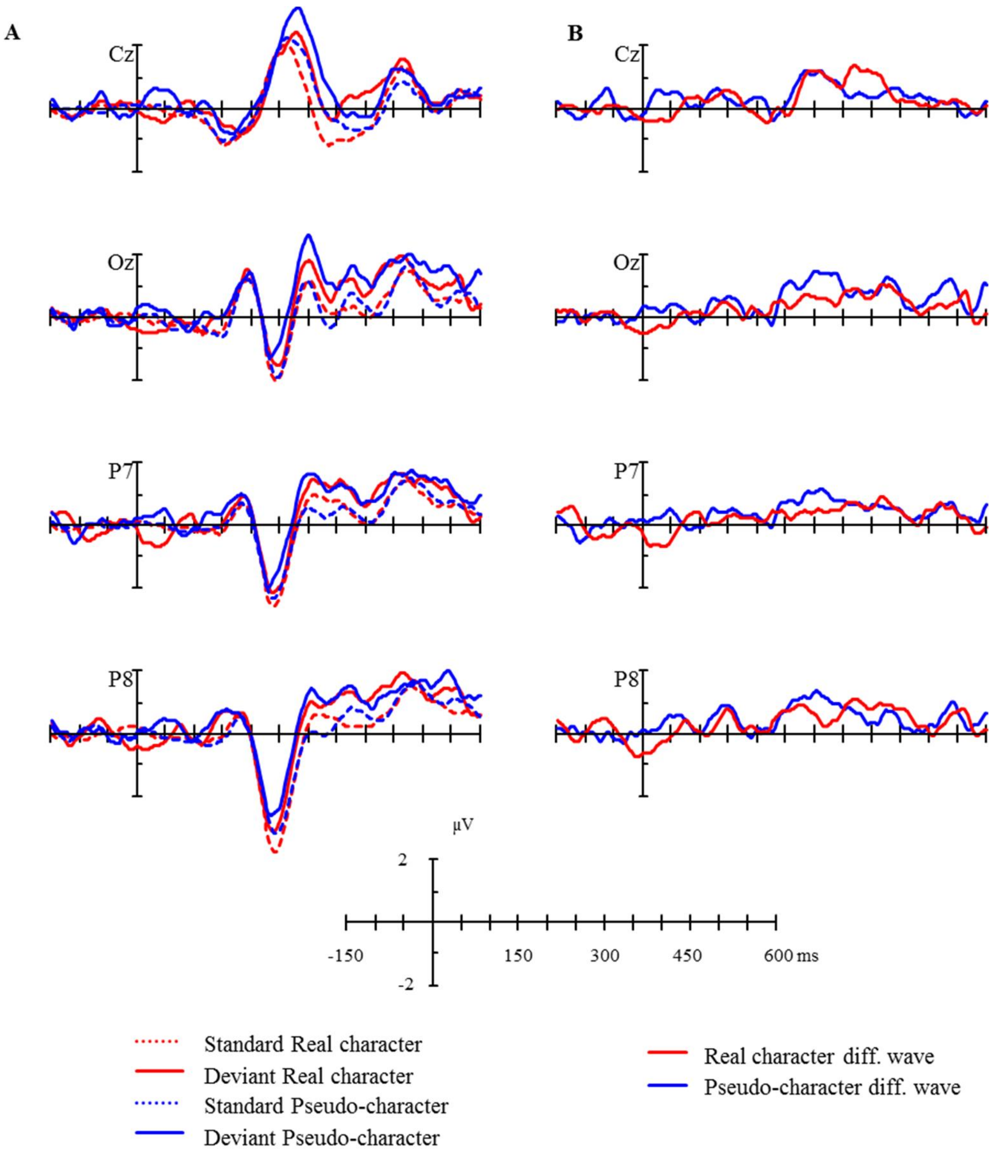


Figure 4.6 Real and Pseudo- character ERP waveforms. (A) ERP waveforms of deviant and standard Real and Pseudo- characters and (B) their difference ERPs. Negativity is plotted downward.

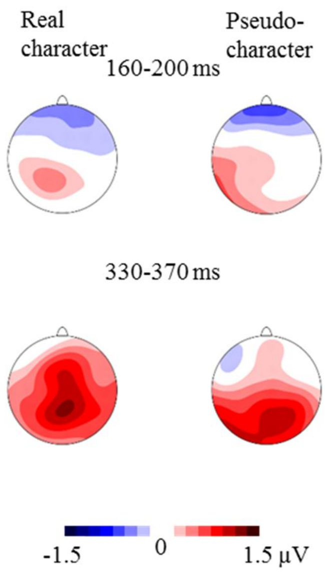


Figure 4.7 Topographical maps of Real (Left) and Pseudo- character (Right) difference ERPs.

160-200 ms. ANOVA did not yield any effects of Type or interaction of factors involving Type, Fs < 1, which suggests no difference between deviants and standards, in midline and lateral analyses.

330-370 ms. ANOVA did not yield any effects of Type or interaction of factors involving Type in either midline or lateral analysis, Fs< 1, which suggests no difference between deviants and standards in midline and lateral analyses.

4.2.3 Discussion

This experiment explored whether vMMN is elicited when real and pseudo-characters are contrasted directly. According to the results, there was no difference between deviants and standards, thus no vMMN was elicited for either real or pseudo-characters.

There may be two reasons for the absence of effects. Firstly, one possible reason may lie in the visuo-physical similarity between these two types of characters. As detailed in Experiment 1, real and pseudo-characters share both compositional radicals and radical legality. The only difference between them lies in how the semantic and phonetic radicals pair with each other. The magnitude of deviance, therefore, may have been not sufficiently large to elicit vMMN. In Czigler et al. (2002), although the pink-black grating and red-black grating were arguably not difficult to distinguish in an active task, still no vMMN was found in comparing them in an attention-limited condition. In a recent vMMN study to investigate the oblique effect (Takács, Sulykos, Czigler, Barkaszi, & Balázs, 2013), the authors demonstrated that a significantly large change between deviant and standard stimuli was necessary for eliciting vMMN. In vision research, the oblique effect is the insensitivity of the perceptual system to oblique as compared to vertical and horizontal (cardinal) line contours. The authors reported that in the Attend condition, deviance of 17º in oblique direction and of 10º in cardinal direction could be reliably detected. However, in the Ignore condition, no vMMN was found by Gabor patches with a 50º orientation change. When the orientation deviance increased to 90º, changes in oblique orientation elicited smaller vMMN than those from cardinal angles, thus producing the classic vMMN oblique effect. Taken together, it seems vMMN can be elicited only when visual deviance reaches a threshold, which may be higher than the magnitude of deviance to be detectable in an attended condition.

Another factor that could have influenced the non-differentiation of deviants and standards is the presentation of multiple tokens of the two types of characters. It is a tenable assumption that the more tokens included in a type of stimuli, the more difficult it is to abstract shared features, because of the capacity limits of human cognitive processing. In Shtyrov et al. (2013), deviants and standards were represented by only one token, with a fixed contrast feature between a deviant and a standard across different blocks. Accordingly, that design presumably made it easier for participants to process difference between deviant and standard stimuli. This might explain to some extent the presence of vMMN in their study and its absence in the current experiment. However, in order to directly test this assumption, an experiment directly manipulate the factors of magnitude of deviance and number of tokens is needed.

4.2.4 Conclusion

In sum, by directly contrasting real and pseudo- characters, the current study reduced the magnitude of deviance between deviants and standards. Using this design, there was no evidence of vMMN. This result may suggest that physical comparison is a basic component of vMMN elicitation (Stefanics, Kremláček, et al., 2014). It may also imply that in order to elicit vMMN, the difference between deviants and standards needs to be sufficiently salient. In addition, multiple members of a type of stimuli may pose difficulty for abstracting common attributes among members, especially in an attention-deprived condition.

4.3 Experiment 3: Examining the influence of attention on lexical vMMN

It was found in Experiment 1 that when attention was directed away from the critical deviant/standard stimuli, lexical vMMNs were apparent in the two intervals before 200 ms and after 300 ms, suggesting that language vMMN might be independent of attention. However, in order to specifically investigate the interaction between language-related vMMN and attention, it is necessary to have a systemic modulation of the direction of attention (to, or away from, the critical eliciting stimuli). Such a clarification is important both theoretically and practically (Stefanics, Astikainen, & Czigler, 2014). In the framework of predictive coding (Clark, 2013; Garrido, Kilner, Stephan, & Friston, 2009), attention can modulate the predictive process by altering the precision. Accurate prediction with attentional support means confidence in prediction errors. From a practical viewpoint, attention can confound mismatch responses (Stefanics, Astikainen, et al., 2014). Therefore, it seems essential to control for attentional bias in identifying possible vMMN effects. In fact, previous studies with both auditory and visual MMN designs have been inconsistent on the issue of attention and mismatch responses (Stefanics, Kremláček, et al., 2014). The current experiment aims to shed some light on this issue by investigating the interaction of attention and language-related deviance detection. Specifically, it will investigate what occurs to mismatch responses when participants' attention is directed to the perifoveal lexical stimuli, with all other experimental procedures kept the same as in the "non-attend" Experiment 1. Secondly, it will explore how attention modulates mismatch responses, by comparing the current results with Experiment 1.

4.3.1 Materials and methods

Participants

Sixteen undergraduate students (mean age: 21.9, SD: 0.85, 9 males) participated in the experiment for course credit. All were right-handed, neurologically heathy and had normal or corrected-to-normal vision. They provided informed written consent before taking part in the experiment. The study was approved by the Research Ethics Committee of the University of Nottingham Ningbo, China.

Stimuli

The same stimuli used in Experiment 1 were adopted.

Procedure

The experimental procedure was the same as in Experiment 1 but with one exception. Here, instead of focusing their attention on the fixation cross changes in the screen centre, participants were asked to detect the perifoveal deviants in each block. They were also instructed to mentally count how many deviants they found in a block and report the answer after they completed the block. By doing this, their attention would be directed to the perifoveal lexical stimuli.

Data recording and analysis

The EEG data were registered using Brain Vision Recorder (Brain Products GmbH, Germany) and a 32-channel EasyCap (EasyCap GmbH, Germany), which was the same as Experiment 2. Therefore data recording and analysis procedures were kept the same as in Experiment 2.

To test the attentional effect on mismatch responses, responses in the current experiment and Experiment 1a were compared in a repeated measures

ANOVA with Lexicality (real vs. pseudo-character difference ERPs) and Region as within-participant factors and Attention (attend vs. ignore) as a between-participant factor.

4.3.2 Results

Behavioural results

The mean counts of detected deviants in this experiment were 61.8, 59.0, 55.9 and 53.7 corresponding to the blocks of real and non-character (deviant vs. standard), non- and real character, pseudo- and non- character, and non- and pseudo- character, respectively.

ERP results

Figure 4.8 (Left) shows the grand-averaged ERPs for the four conditions of standard and deviant real characters, standard and deviant pseudo- characters, at the electrodes of Cz, Oz, P7, P8. Figure 4.8 (Right) shows the deviant-minus-standard difference waves of real and pseudo characters at the four electrodes. It appears that real characters elicited larger early negativity than pseudo-characters before 300 ms. In the time window of 300-400 ms, there seems to be no clear difference between real and pseudo- character negativities. From 500 ms on, both real and pseudo- characters yielded large positivity. The corresponding topographical maps of the difference waves are also plotted in Figure 4.9.

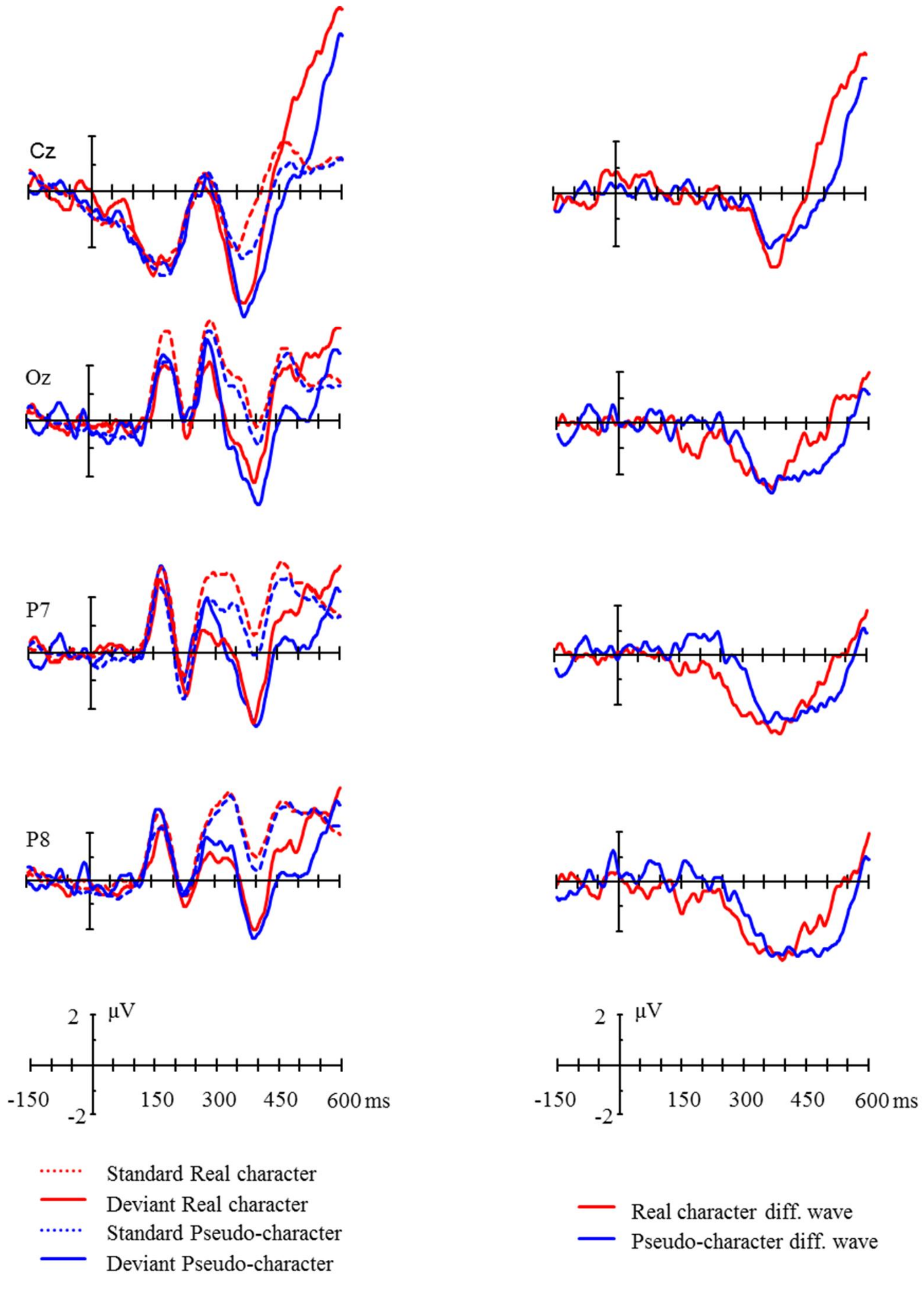


Figure 4.8 Real- and pseudo- character ERP waveforms and topographical maps. ERP waveforms of deviant and standard real and pseudo-characters (Left), and their difference (deviant minus standard) ERPs (Right). Negativity is plotted downward.

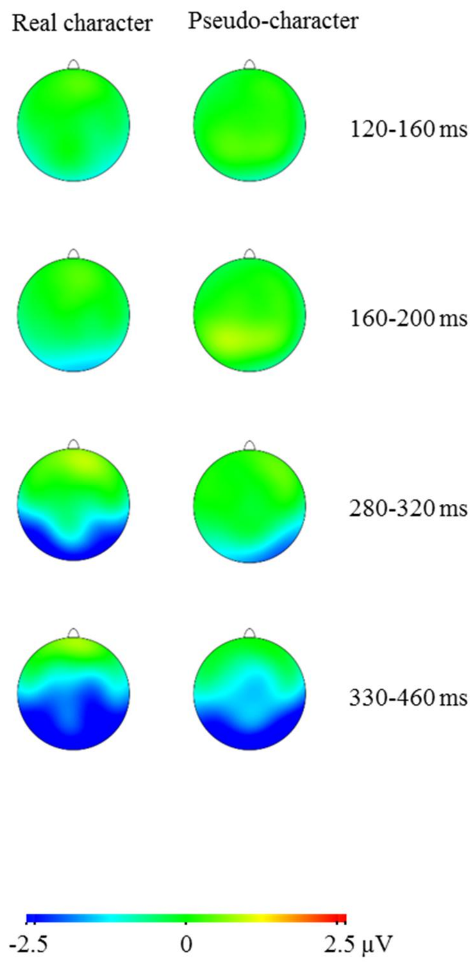


Figure 4.9 Topographical maps for Real and Pseudo- character difference ERPs.

Comparison of deviants and standards

120-160 ms. There were no reliable effects in this time interval.

160-200 ms. ANOVA in the midline analysis yielded an interaction of Type, Lexicality and Region, $F(3,45) = 4.03$, $p < 0.05$, partial $\eta^2 = 0.21$. Post hoc analysis indicated less positivity of real character deviants than standards at the occipital electrode, 1.91 vs. 3.03 μV, $t(15) = -2.27$, $p < 0.05$. ANOVA in the lateral analysis also yielded an interaction of Type, Lexicality and Region, $F(2,30) = 5.07$, $p < 0.05$, partial $\eta^2 = 0.25$. However, in post hoc analysis, no reliable effects were observed.

280-320 ms. In the midline electrodes, ANOVA yielded an interaction of Type and Region, $F(3,45) = 4.23$, $p < 0.05$, partial $\eta^2 = 0.22$. Post hoc analysis indicated that deviants were less positive than standards at the occipital site, 1.50 vs. 2.90 μV, $t(15) = -2.76$, $p < 0.05$. In the lateral analysis, ANOVA yielded an interaction of Type and Region, $F(2,30) = 10.56$, $p < 0.01$, partial $\eta^2 = 0.41$. Post hoc analysis suggested less positivity of deviants than standards at parietal-occipital area, 1.59 vs. 2.94 μV, $t(15) = -2.64$, $p < 0.05$.

330-460 ms. In the midline sites, ANOVA yielded a main effect of Type, $F(1,15) = 15.14$, $p < 0.01$, partial $\eta^2 = 0.50$. Post hoc analysis suggested more negativity in deviants than standards, -1.50 vs. -0.03 μV. In the lateral analysis, ANOVA yielded an interaction of Type and Region, $F(2, 30) = 4.12$, $p = 0.05$, partial $\eta^2 = 0.22$. Post hoc analysis suggested that deviants were more negative than standards in all the three regions, $ps < 0.05$.

Attentional effect on the mismatch responses

Figure 4.10 and Figure 4.11 show the difference ERPs and topography for real and pseudo- characters in the Ignore and Attend conditions. Attention appears not to modulate the mismatch responses until later stages after 300 ms. In particular, attention appears to increase positivity in both real and pseudo-characters after 500 ms at central and posterior sites.

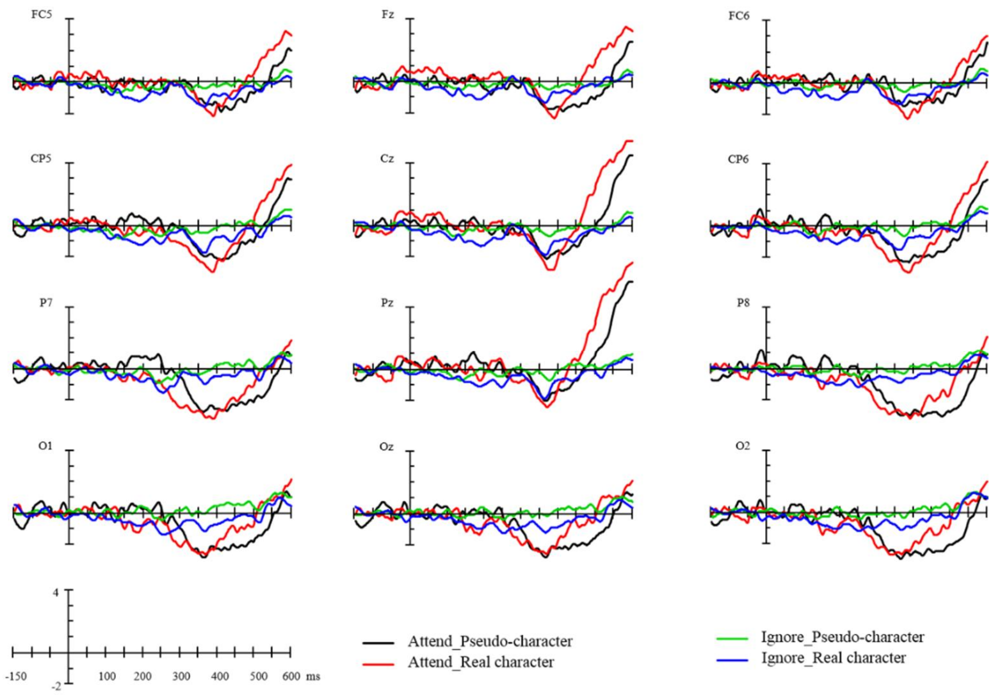


Figure 4.10 Comparisons of the difference ERPs of real and pseudo-characters in the Attend and Ignore conditions.

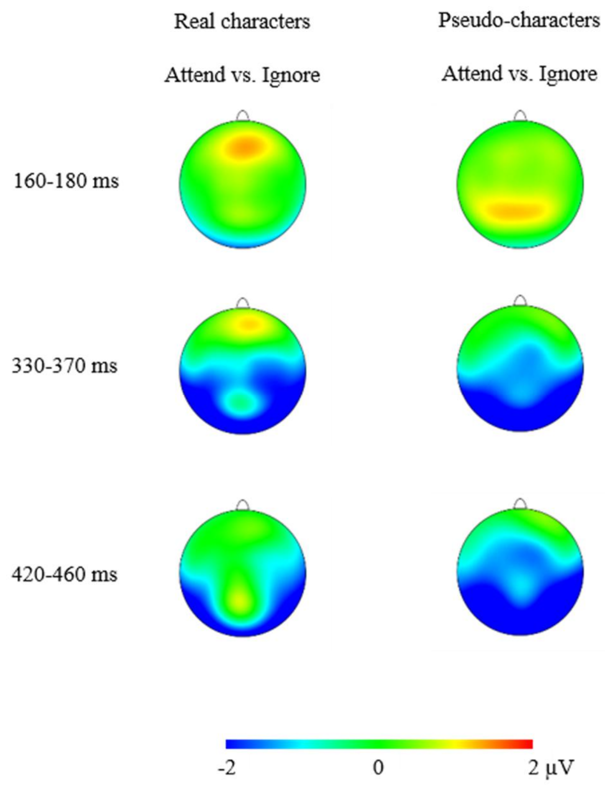


Figure 4.11 Topographical maps of attentional effects in real (Left) and pseudo-characters (Right).

160-180 ms. In the midline analysis, ANOVA yielded an interaction of Attention, Lexicality and Region, $F(3,102) = 3.08$, $p < 0.05$, partial $\eta^2 = 0.08$. Post hoc analysis suggested that real characters tended to be more positive in the Attend than Ignore condition at the frontal site, Attend vs. Ignore, 0.30 vs. -0.95 μV, $p = 0.06$; and pseudo-characters were more positive at the parietal site when attention was directed to the linguistic stimuli, Attend vs. Ignore, 0.98 vs. -0.29 μV, $p < 0.05$. In the lateral analysis, ANOVA yielded an interaction of Attention, Lexicality and Region, $F(2,68) = 3.9$, $p < 0.05$, partial $\eta^2 = 0.10$. Post hoc analysis found that real characters were similarly negative between the two conditions, ps > 0.1, except at the frontal site where they tended to be more positive in the Attend than Ignore conditions, $p = 0.08$. Pseudo-characters tended to be more positive in all the three areas with attention, ps < 0.1

330-370 ms. In the midline analysis, the interactions between Attention and Lexicality and between Attention, Lexicality and Region did not reach significance. ANOVA also yielded a marginally significant interaction of Attention and Region, $F(3,102) = 3.30$, $p = 0.06$, partial $\eta^2 = 0.09$. Post hoc analysis suggested more negativity in the occipital site in the Attend than Ignore condition, -2.43 vs. -0.49 μV, $p < 0.05$. In the lateral analysis, ANOVA yielded an interaction of Attention and Region, $F(2,68) = 10.17$, $p < 0.01$, partial $\eta^2 = 0.23$. Post hoc analysis indicated that attention to linguistic stimuli increased negativity at Central ($p < 0.05$) and Parietal ($p < 0.01$) areas. ANOVA also yielded a marginally significant main effect of Lexicality, $F(1, 34) = 3.15$, $p = 0.08$, partial $\eta^2 = 0.08$, which was due to more negativity in the real than pseudo-character condition (-1.36 vs. -0.79 μV).

420-460 ms. In midline analysis, ANOVA yielded an interaction of Attention and Lexicality, $F(1,34) = 6.56$, $p < 0.05$, partial $\eta^2 = 0.16$. Post hoc analysis indicated that with attentional resources, more negativity was elicited by pseudo-characters (-1.45 vs. 0.11 μV, $p < 0.05$) while no difference was found between the Attend and Ignore conditions for real characters (-0.34 vs. -0.62 μV, $p > 0.1$). In lateral analysis, ANOVA yielded a marginally significant interaction of Attention and Lexicality, $F(1,34) = 3.64$, $p = 0.06$, partial $\eta^2 = 0.10$. Attention increased negativity in pseudo-characters, -1.65 vs. 0.13 μV, $p < 0.01$ while similar negativity was observed for real characters, -1.07 vs. -0.54 μV, $p > 0.1$). The interaction between Attention and Region also reached significance, $F(2, 68) = 4.36$, $p < 0.05$, partial $\eta^2 = 0.11$. Further analysis suggested that attention significantly increased negativity in central and parietal areas, ps < 0.05.

4.3.3 Discussion

This experiment aimed to investigate how real and pseudo-characters are processed when attention is directed to them and how attention may modulate mismatch responses to lexical information, by comparing the current results with Experiment 1 where attention was directed away from the stimuli.

In the Attend condition, at 160-200 ms, only real characters elicited negative difference ERPs (vMMN) in the occipital area. In the interval of 280-320 ms, real and pseudo- characters elicited similar vMMN in the middle occipital and lateral parietal-occipital areas. Later at 330-340 ms, again both real and pseudo-character elicited vMMNs which did not differ in amplitude.

In the 160-200 ms window, with attention, overall, more positivity was elicited by real characters in the frontal area and pseudo-characters in middle parietal area and lateral sites. In particular, real character vMMN was restricted to the occipital site. After 300 ms, overall, attentional resources increased vMMN in real and pseudo- characters. In particular, in the 420-460 ms interval, pseudo-characters elicited significantly larger vMMN in the Attend than Ignore condition, while no difference between the two conditions was found for real characters.

Attentional effect in the early interval before 200 ms

In this early interval, with a direct attentional focus, real character vMMN seem to be reduced to the occipital site while pseudo-characters show no signs of vMMN. This counter-intuitive result runs contrary to the hypothesis that with attentional resources, real and pseudo-characters should both yield early vMMN of similar size. In the auditory domain, studies have shown that acoustic attribute changes can elicit MMN of similar amplitude independently of attention (Näätänen et al., 2007; Shtyrov et al., 2010). Shtyrov et al. (2010) investigated the attentional influence on lexical MMN by manipulating attentional focus on auditory words and pseudo-words. In the early window around 120 ms, real words elicited similar MMN irrespective of attentional conditions while pseudo-words yielded increased MMN in the Attend condition to the extent there was no difference from the real word MMN. Therefore, it was claimed that the early MMN of real words may have a certain degree of automaticity. In the visual modality, usually attention is manipulated by changing the difficulty of the central distraction task so that the attentional resources involuntarily captured by the vMMN-eliciting stimuli in the periphery can be modulated (Heslenfeld, 2003; Kimura & Takeda, 2013; Kremláček et al., 2013; Pazo-Alvarez, Cadaveira, & Amenedo, 2003). Though not unequivocal as to whether the early vMMN may be subject to attentional modulation, these studies seem to suggest that vMMN can be elicited at least with an easy task/more attention to the critical stimuli. Kremláček et al. (2013) displayed perifoveal visual radial motions and instructed participants to ignore them and focus on a central number detection task of three different levels of difficulty. vMMN of similar size was found in all conditions. In another study, Pazoalvarez, Amenedo, and Cadaveira (2004) presented moving gratings in the perifoveal field in passive oddball sequences and manipulated the attentional load in a central task. In this study, vMMN was also reportedly present regardless of attentional levels.

The current discrepant result might be related to the specific way of attention manipulation. Instead of changing attentional loads by manipulating the central task difficulty and maintaining central focus as mentioned above, the current experiment directly oriented the attentional focus from the central task to the perifoveal stimuli (i.e., attend perifoveal stimuli). In early active processing of deviant and standard perifoveal stimuli, visual executive attention might inhibit the early automatic deviance detection. The frontal positivity in real characters and overall positivity increase in the Attend condition might suggest such an attentional shift and suppression. However, the real characters seem to "survive" this suppression to some extent, as evidenced by the presence of vMMN at the midline occipital site. This may be attributed to the robustness of the underlying interconnected neuronal circuits supporting the activation of lexical representations. Recently, Kuldkepp et al. (2013) compared the detection of deviant visual motion flow direction in "attended" and "unattended" conditions. Similarly to the current experiment, participants needed to focus on the stimuli in the periphery in the attended condition and to monitor the central stimuli in the unattended condition. In this study, no early vMMN was found in the Attend condition either. In the visual domain, attention thus seems to influence the appearance of early vMMN to both real and pseudo- characters. Future work, therefore, is needed in order to elucidate how the two types of attentional manipulation discussed above may differ in influencing the early elicitation of vMMN.

On the other hand, consistent with studies in both visual and auditory MMN studies (for reviews, see Näätänen et al., 2007; Pulvermüller & Shtyrov, 2006; Stefanics, Kremláček, et al., 2014) , in a non-attend condition, vMMN was reliably elicited in the experiment by real meaningful stimuli in the early interval before 200 ms (Experiment 1), in contrast to the weakened or null vMMN effects in the Attend condition. This may imply that an unattended "passive" design is particularly important and useful to investigate the automatic detection of not only perceptual objects but also linguistic stimuli, as indexed by vMMN elicitation.

Attentional effects after 330 ms

In the interval of 330-370 ms, with attentional resources, both real and pseudo-characters elicited vMMNs which did not differ. In a later interval of 420-460 ms, pseudo-characters even yielded more negativity than real characters. This appears to be caused by the significant increase of vMMN in pseudo-characters when compared with their counterparts in Ignore condition. This pattern of result is consistent with findings in the auditory domain (Garagnani et al., 2009; Shtyrov et al., 2010) documenting the pseudoword enhancement and real word stability in an attended context in later windows after 200 ms. In Shtyrov et al. (2010), pseudowords elicited larger MMN with attentional support, while real word MMNs were similar in the attend and non-attend conditions. Thus, current studies suggest a significant role of attention in modulating mismatch responses of pseudo-words in particular, regardless of presentation modalities. Given their strong lexical representations, real characters can be activated to their full potential regardless of attentional levels. For pseudo-characters however, the absence of memory representations results in weak or no activation under the non-attend condition, resulting in the lack of vMMN. With attentional resources, as seen in the current experiment, intensified lexical analysis of the pseudo-character stimuli is likely, especially after the initial search for corresponding lexical entries becomes futile. Such processing effort may lead to the enhanced amplitude of vMMN. This pattern is reminiscent of the enlarged N400 effect in pseudowords against real words. In fact, the pseudo-character enhancement occurring only in the Attend condition is also consistent with the controlled nature of linguistic processing indexed by the N400 component as seen in previous studies (Bentin, Kutas, & Hillyard, 1995; Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995). Supporting this proposal, a recent neuro-computational model of interactions between lexical processing and attention also demonstrates a similar dynamic pattern of word-pseudoword responses subject to attentional changes (Garagnani, Wennekers, & Pulvermüller, 2008).

4.3.4 Conclusion

In this experiment, when attention was directly oriented to the perifoveal stimuli, in the early interval no vMMN was found for either real and pseudo- characters, while after 330 ms, both types of character elicited vMMN of similar amplitude, possibly due to the increased vMMN of the pseudo-characters. Comparing these results with those of Experiment 1, it is clear that the appearance of both early and late vMMN can be influenced by attention. Specifically, with attention, more mismatch positivity is elicited by both real and pseudo- characters and the early vMMN of real characters can be reduced to the occipital site. In the later intervals after 330 ms, attention boosts pseudo-character vMMN effects while it has no effect on real character vMMN.

4.4 Experiment 4: Lexical frequency effects on vMMN

It was seen from Experiment 1 that lexical information can be processed early and automatically, as demonstrated by the presence of vMMN for real characters. This is presumably made possible by the availability of long-term memory representations for real characters. It is thus predictable that words of different frequency of occurrence may have representations which are different in strength. Indeed, previous auditory MMN studies have found evidence of larger MMN for HF than LF words in Russian and Finnish (Alexandrov et al., 2011; Shtyrov et al., 2011). Such a discrepancy should be reflected in the visual modality too. The current experiment attempts to test this prediction, using the neurophysiological index of vMMN. Specifically, HF words are expected to have larger vMMN amplitude relative to LF words.

4.4.1 Materials and methods

Participants

Twenty-one neurologically healthy right-handed native speakers of Chinese, with normal or corrected-to-normal vision, took part in the experiment (age range: 18-26, mean: 21.0; 18 males) for course credit. The research protocol was approved by the Research Ethics Committee of the University of Nottingham Ningbo, China. All of them provided their informed written consent.

Stimuli

A preliminary set of 15 HF and 15 LF characters were chosen from SCWD (Liu, Shu, & Li, 2007). Twenty native Chinese speakers (10 females, participants in the ERP experiment not included) from the same university were asked to do a computerised norming study on a scale of 1-7 (with 7 meaning most frequent/concrete/arousing/positive). Based on the ratings, five HF and five LF characters were selected. The two conditions differed significantly in frequency (6.44 vs. 2.85, $p < 0.0001$) but were similar ($ps > 0.1$) in concreteness (3.39 vs. 3.61) and arousal (2.61 vs. 2.82). In terms of valence, both conditions were rated to be more or less neutral, although the LF condition was slightly lower than HF condition (4.18 vs. 3.78, $p < 0.05$). The HF and the LF conditions were also similar in averaged value of visual complexity (stroke numbers, 8.20 vs. 8.20) and phonetic regularity (-0.40 vs. -0.20). See Table 4.3 for a list of the stimuli.

Table 4.3 A list of HF and LF characters

	High frequency condition				
Characters	是	里	时	要	说
Pinyin	shi4	li3	shi2	yao4	shuo1
Gloss	*yes*	*inside*	*time*	*need*	*talk*
	Low frequency condition				
Characters	弈	疙	赁	扪	弧
Pinyin	yi4	ge1	lin4	men3	hu2
Gloss	*play chess*	*pimple*	*hire*	*pat*	*arc*

Procedure

The procedure was similar to Experiment 1. One difference, however, was that in the current experiment, the distraction task was only to track any colour changes by pressing a key in the keyboard as quickly and accurately as possible. Participants were not ask to count and remember the number of cross changes.

In block one, HF characters acted as standards and LF characters as deviants and their roles were swapped in the other block. Similar to Experiment 2, here difference ERPs are also computed by directly comparing deviants and standards across the two blocks. However, the magnitude of stimulus change here should be larger than that in Experiment 2 since all the stimuli in the current experiment are different character identities, in contrast to Experiment 2 where exactly the same radicals are used for all the critical stimuli. The deviance size here is therefore assumed to be suitable for eliciting vMMN.

In each block there were 300 standards and 50 deviants. Both blocks were initiated by three standards whose data were not included in the analyses. The order of blocks was randomised among participants. In each block, however, the sequence of presentation was pseudo-randomised in order to make sure that the same characters did not appear in neighbouring presentations; no two sequential character presentations belonged to one frequency condition; at least two standards existed between two deviants. A practice session was given before the experiment in order to familiarise participants with the task.

EEG recording and ERP analysis

Electroencephalogram (EEG) was registered using Brain Vision Recorder software (Brain Products GmbH, Germany) with a sampling rate of 500 Hz, and a band-pass from 0.01 to 100 Hz. All electrodes were referenced to the nose tip. All impedances were maintained at or below 5 kΩ. The acquired data were processed using Brain Vision Analyzer (Brain Products GmbH, Germany). First, the data was filtered between 1-30 Hz (24 dB/Octave) with a finite impulse response (FIR) filter (Butterworth zero phase filters). Ocular artifacts were corrected using algorithm (Gratton et al., 1983). Continuous data with signal amplitudes surpassing an absolute value of 100 µV were excluded. Finally, the data were segmented from -100 to 600 ms relative to the stimuli onset with a 100 ms baseline. The segments of standards and deviants of HF and LF characters were averaged for further analysis. In the averaging procedure, the first 3 trials in each block, trials where participants gave a response, and trials where there was fixation cross colour change, were rejected.

Overall, HF difference ERPs appeared to be elicited earlier than those of the LF group. While no amplitude difference was found between LF deviants and standards before about 300 ms, visible amplitude difference between HF deviants and standards appeared at an early onset (Figure 4.12). Based on previous studies with similar oddball paradigms in auditory (Alexandrov et al., 2011; Shtyrov et al., 2011) and visual presentation mode (Shtyrov et al., 2013), time windows and electrode clustering were selected as follows: two early windows of 120-150 ms and 200-300 ms were chosen for HF characters while two late windows of 300-350 ms, 350-400 ms were chosen for both HF and LF characters (Figure 4.13). For mean amplitude calculation, Region included frontal (F3, F4, Fz), central (C3, C4, Cz), parietal (P3, P4, Pz) and occipital (O1, O2, Oz) clusters. Repeated measures analysis of variance (ANOVA) of Type (Standard vs. Deviant) and Region (four clusters) and Condition (HF vs. LF) was conducted for the selected windows. All the ANOVA analyses incorporated Greenhouse-Geisser correction for violations of sphericity.

4.4.2 Results

Behavioural performance

Mean reaction times were similar ($p > 0.05$) for the block with HF deviants (417.9 ms, SD = 43.3) and LF deviants (412.0 ms, SD = 36.8). However, the hit rate in the block with LF standards (99.5%, SD = 0.01) was higher than that in the block with HF standards (95.0%, SD = 0.01), and this difference reached significance ($p < 0.001$). No false alarms in either block were found.

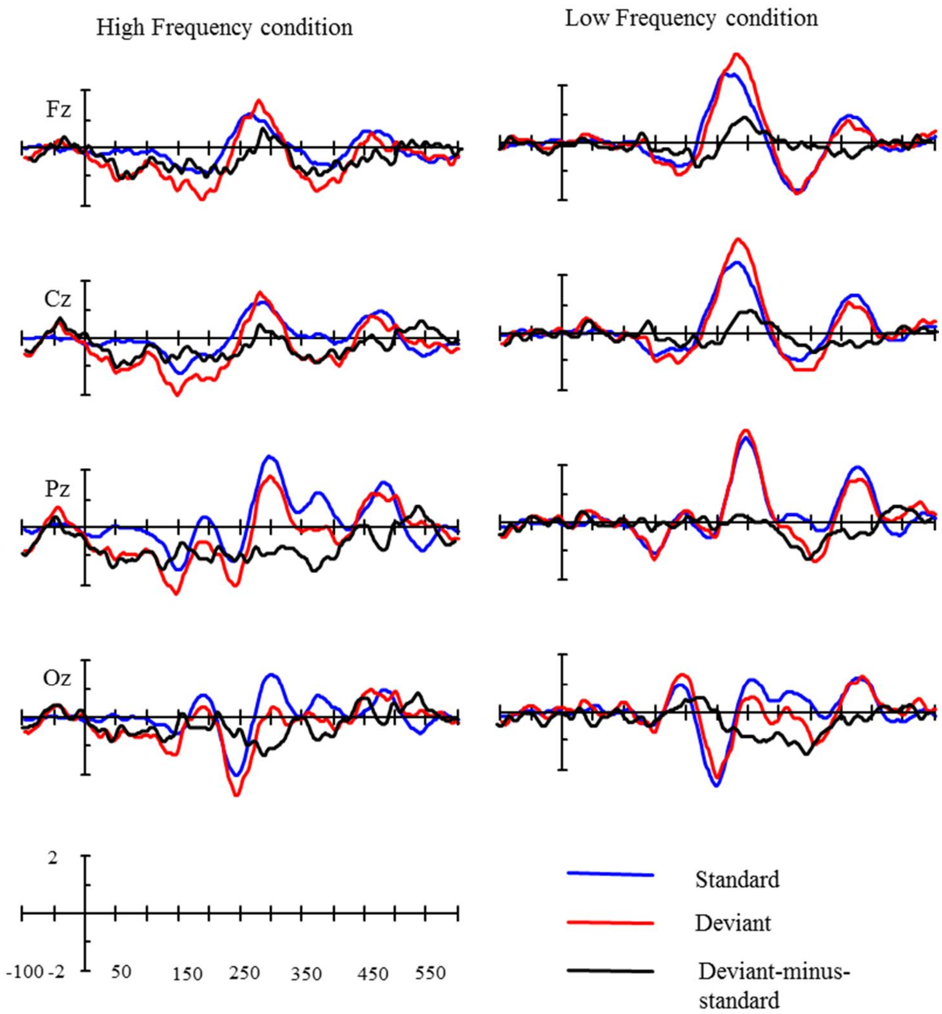


Figure 4.12 ERPs to standard and deviant characters and the difference (deviant-minus-standard) ERPs. Left: ERPs to the HF character condition. Right: ERPs to the LF condition. Negativity is plotted downward.

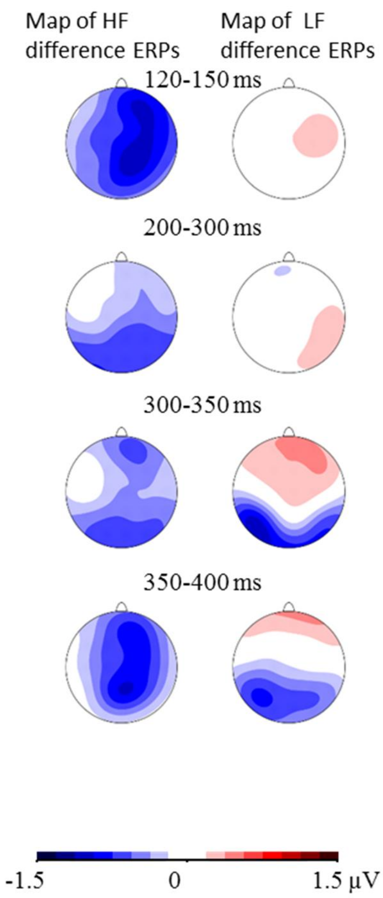


Figure 4.13 Topographical maps of HF (Left) and LF (Right) difference (deviant-minus-standard) ERPs.

ERP results

120-150 ms. ANOVA yielded an interaction of Type and Frequency, $F(1, 20) = 5.23$, $p < 0.05$, partial $\eta^2 = 0.21$. Post hoc analysis suggested that while deviant and standard stimuli were more negative than for the HF condition, i.e., vMMN, $p < 0.01$, there was no difference between deviant and standard LF stimuli, $p > 0.05$.

200-300 ms. ANOVA yielded an interaction of Frequency, Type and Region, $F(3, 60) = 4.01$, $p < 0.05$, partial $\eta^2 = 0.17$. Post hoc analysis showed that deviants were more negative than standards (vMMN) for HF characters in parietal ($p = 0.07$) and occipital ($p < 0.05$) areas. However, there was no difference for LF deviant and standard characters, $p > 0.05$.

300-350 ms. ANOVA yielded an interaction of Frequency, Type and Region, $F(3, 60) = 5.57$, $p < 0.01$, partial $\eta^2 = 0.22$. Post hoc analysis showed that significant differences between deviants and standards occurred only for LF characters at the occipital area, $p < 0.05$.

350-400 ms. ANOVA yielded an interaction of Frequency, Type and Region, $F(3, 60) = 2.79$, $p = 0.09$, partial $\eta^2 = 0.12$. For HF characters, deviants tended to be more negative than standards at frontal ($p = 0.07$) and central ($p = 0.06$) areas and less positive than standards at parietal ($p = 0.06$) and occipital ($p < 0.05$) areas. For LF characters, deviants were more negative than standards in parietal and occipital areas ($ps < 0.05$). To compare the vMMNs of HF and LF characters, an ANOVA was carried out with factors Frequency (HF and LF difference ERPs) and Region (four clusters). There were no significant main effects of Frequency or interaction of Frequency and Region (both $ps > 0.05$), which suggested that similar vMMN amplitudes were elicited by HF and LF characters in this interval.

4.4.3 Discussion

This experiment aimed to explore early and automatic processing of visually-presented Chinese characters of different lexical frequency values. In a reversed oddball paradigm, mismatch responses to HF and LF characters were measured by comparing deviants and standards of the same frequency condition across the two blocks. Behaviourally, while there was no difference between HF and LF character blocks in terms of reaction times, the hit rate in the block with LF character standards was found to be higher than that in the block with HF character standards. The high hit rate in both blocks (above 95%) suggested that participants indeed conformed to the experimental instruction and attended to the distraction task. The relatively lower hit rate in the block with HF standards seems to suggest that the HF characters may have interfered with the primary task of fixation cross detection. In terms of the difference ERPs, HF character vMMNs were found at the 120-150 ms and 200-300 ms intervals. In contrast, LF vMMN was shown at a later window of 300-350 ms. Both HF and LF characters elicited similar amplitudes of vMMN at 350-400 ms.

Though with a clear difference in time intervals, vMMN was elicited by both HF and LF character conditions in the experiment. This finding is consistent with a recent vMMN study using alphabetic Russian words (Shtyrov et al., 2013), suggesting vMMN can be elicited by visual-orthographic stimuli.

To the author's knowledge, this is the first time that the lexical frequency effect on vMMN has been investigated for visually and perifoveally presented linguistic stimuli. The robust vMMN effect for HF characters cannot be attributed to physical/orthographic differences. There is no visuo-orthographic contrast between the two conditions. HF and LF characters were matched in overall physical features in terms of number of strokes as well as other variables such as phonetic regularity, concreteness, arousal and valence. Therefore a frequency-based account of the mismatch response best explains the results. Previous studies have documented neurophysiological evidence of fast, early lexical frequency effects within 200 ms after stimulus onset in the auditory modality (Assadollahi & Pulvermüller, 2003; Penolazzi et al., 2007). In terms of time course of the effect, the current finding of HF character vMMN at 120-150 ms fits well with these results. Indeed, in a recent MEG study, also in a similar attention-deprived setting but without repetition, real words were found to elicit higher amplitude than pseudo-words within 100 ms (Shtyrov & MacGregor, 2016). The HF advantage also agrees with two recent auditory MMN studies exclusively investigating frequency effects (Alexandrov et al., 2011; Shtyrov et al., 2011), both of which demonstrated lexical frequency effects before 200 ms. Taken together, these studies suggest early lexical frequency effects independent of the mode of presentation.

As to the mechanism behind these effects, it is possible that the more robust neuronal ensemble and the correspondingly stronger memory representations for HF characters enable more intense activation than for LF characters, especially in a non-attend context (Alexandrov et al., 2011; Shtyrov et al., 2011). For the LF characters, the neuronal activation would be reduced and weaker in strength due to their infrequent occurrence in daily language use, hence the absence of vMMN in the early latency range. Since the current experiment applied a non-attend design with no task of lexical relevance, the early lexical processing could be claimed to be automatic.

The lexical frequency effect in early vMMN elicitation can be regarded as a refinement of the "rough" lexicality MMN effect as shown in a number of previous auditory studies (for a review see, Pulvermüller & Shtyrov, 2006). In the current experiment, there is a considerable frequency gap between the HF and LF characters, as reflected in the rating of frequency value. This seems to imply that a sharp frequency contrast of lexical stimuli might be a prerequisite for a difference in (v)MMNs to emerge. Support for this view can be found from a recent vMMN study on lexical tone processing of Chinese characters (Wang, Wu, et al., 2013). The authors did not find a frequency effect in vMMN amplitudes, when comparing two blocks with HF homophones ("620 and 35 per million") with another two blocks with LF homophones ("46 and 44 per million”). The frequency difference in this study is far narrower than that of the current study (5584 vs. 1 per million according to SCWD) and that of an auditory MMN study (Alexandrov et al., 2011) (“569.14 vs. 4.22” per million). The differences between the current experiment and that of Alexander and colleagues might also have led to different results concerning LF stimuli: while the LF words elicited MMN (albeit smaller relative to the HF word) before 200 ms in their work (Figure 3), no early vMMN was found for LF characters in the present experiment. This being tentatively argued, future study is needed to clarify the potential importance of the frequency value gap between deviants and standards and its relevance to long term memory trace strength.

After the initial early interval, HF characters were found to elicit vMMNs at later windows of 200-300 ms and 350-400 ms, while LF characters yielded vMMN from 300-400 ms. Since the human visual system is characterised by hierarchical architecture and feedback connections (Czigler, 2013), the vMMNs at several intervals for the HF condition in the current study may imply an involvement of more than one processing level in the whole hierarchical structure. The later effects for both HF and LF characters featured a similar but broader topographical distribution than the earlier effect before 200 ms, with the HF character vMMN spreading across the whole analysis area and the LF one focusing on parietal and occipital areas. This topographical characteristic in this time window is reminiscent of the lexico-semantic N400 component, as found in studies with Chinese characters and words (Wang et al., 2010; Zhang, Zhang, & Kong, 2009). Therefore, it is possible that a secondary and deeper lexico-semantic analysis might be reflected in the difference deflections at the later stages, in comparison with the initial processing before

200 ms.

4.4.4 Conclusion

To investigate early and automatic lexical frequency processing in a visual modality, the current study adopted a vMMN paradigm where deviants and standards belonging to one frequency category were contrasted. High-frequency characters elicited vMMN very early (before 150 ms) while low-frequency stimuli vMMN emerged after 300 ms. The vMMN elicitation contrast may be attributed to the difference in memory trace strength for characters which have a sharp contrast in lexical frequency values.

4.5 Experiment 5: Investigating semantic vMMN

While the previous Experiments 1-4 have focused on lexical (single-character word form) processing, the current experiment will move to word meaning processing. Since previous auditory MMN studies have found evidence for automatic semantic processing (Pulvermüller et al., 2005; Shtyrov et al., 2004), Experiment 5 aims to investigate automatic semantic (character meaning) processing in the visual modality, by comparing concrete and abstract characters in terms of their possible elicitation of vMMN. Previous behavioural studies have supported the *concreteness effect*, that is, concrete words are behaviourally responded to more quickly and accurately than abstract words (e.g., Paivio, 1991; Schwanenflugel, 1991). In ERP studies, the concreteness effect is exhibited as a larger N400 with a wider topographical distribution for concrete words compared with abstract words (e.g., Holcomb, Kounios, Anderson, & West, 1999). In addition, there is more activation in the right hemisphere for concrete words, interpreted as reflecting the involvement of a non-verbal image-based processing system (Binder, Westbury, Mckiernan, Possing, & Medler, 2005; Jessen et al., 2000; but see Fiebach & Friederici, 2004). These findings tend to support the dual-coding theory of the concreteness effect (Paivio, 1991). According to this theory, the processing advantage of concrete words is attributed to the two systems they invoke: the verbal and imagery systems (See Chapter 2 for a more detailed description of relevant theories). Overall, based on the previous findings, it is hypothesised that both concrete and abstract characters may elicit vMMNs. However, it is expected that concrete characters may yield larger vMMN than abstract characters. In addition to the normal ERP analysis, time-frequency analysis will also be carried out. As previously few studies have investigated the neuronal oscillatory dynamics of concrete and abstract words, no specific hypothesis can be formulated about this issue. However, based on previous time-frequency studies on language comprehension, especially the role of theta band spectral power and alpha power decrease in semantic processing (Bastiaansen et al., 2012; Bastiaansen et al., 2008; Klimesch et al., 1999), it is tentatively predicted that concrete characters may elicit larger theta power increase than abstract characters, which in turn may have larger alpha power decrease than concrete characters. For a relatively detailed introduction of semantic processing from the perspective of time-frequency analysis, the reader is advised to refer to "Time-frequency analysis in language studies" in section 2.6 of this thesis.

4.5.1 Materials and methods

Participants

Twenty-five college students (average age: 21.5, SD = 1.2, 8 males) participated in the experiment for course credit or for interest. They were all right-handed native speakers of Chinese and reported neurologically healthy and normal or corrected-to-normal vision. They gave written informed consent before the experiment. The study was approved by the Research Ethics Committee of University of Nottingham Ningbo China.

Stimuli

The stimuli included a set of five concrete and five abstract Chinese single-character words, selected from a pool of 15 concrete and 15 abstract characters. This pool of characters, with similar averaged ratings in the number of strokes, frequency (counts per million), phonetic regularity, concreteness, familiarity and imaginability were chosen from the online SCWD database (Liu, et al., 2007). Twenty college students, who did not take part in the ERPs experiment, were then invited to carry out a rating task judging the characters in terms of emotional valence, arousal, frequency and concreteness on a seven-point Likert Scale (1 meaning least positive, arousing, frequent or concrete). Based on the rating scores and data from the database, finally, the ten characters, five for each semantic category, were chosen. The two sets were significantly different in concreteness ($p < 0.001$) but similar in the other dimensions (all *ps* > 0.05) (See Table 4.4 for a list of the stimuli).

Table 4.4 A list of concrete and abstract characters

Stimuli	**1**	**2**	**3**	**4**	**5**
Abstract	势	邦	宙	程	政
Pinyin	shi4	bang1	zhou4	cheng2	zheng4
Gloss	*trend*	*state*	*universe*	*procedure*	*politics*
Concrete	蚕	桃	岛	舌	绳
Pinyin	can2	tao2	dao3	she2	sheng2
Gloss	*silkworm*	*peach*	*island*	*tongue*	*rope*

Procedure

The experimental trials ran similarly to Experiment 1. However, the distraction task was different. Instead of only red-colour changes in Experiment 1, there were two different fixation crosses, in green and red, unpredictably interspersed in a stream of black crosses in the middle screen. The participants' task was to press the correct keys corresponding to each of the two colours, that is, "D" for those crosses in green and "K" for those in red. In the other block, the key-colour correspondence was swapped. Both response speed and accuracy were encouraged. See Figure 4.14 for the procedure. (Note. It was found in Experiments 1 and 2, there were a few participants who felt sleepy in counting red-cross changes. So here, I changed the former counting task into a dual-response task, which demanded more vigilance in completing the experiment).

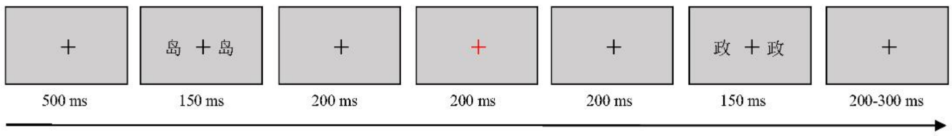


Figure 4.14 Illustration of the experimental procedure. Participants were asked to detect fixation colour change as accurately and quickly as possible by pressing corresponding keys on the keyboard.

EEG recording and ERP analysis

A 32-channel Brain Vision Recorder (Brain Products GmbH, Munich, Germany) (sampling rate 500 Hz, online band-pass filters at 0.01-100 Hz) was used to record electrophysiological (EEG) data. The reference electrode was attached to the tip of the nose. Horizontal and vertical electrooculography (EOG) were monitored using two electrodes placed on the outer canthi of the left eye and below the right eye, respectively. Impedances of all the electrodes (except EOGs which were below 10 kΩ), were maintained below 5 kΩ. In processing the data offline using Brain Vision Analyzer (Brain Products GmbH, Munich, Germany), a baseline of 100 ms prior to and 600 ms after the stimulus event was adopted. Butterworth Zero Phase digital shift (bandwidth 0.1-30 Hz, slope 24dB/Octave), was used to filter data. Artifacts, including eye blinks, movement or muscle potentials, exceeding an absolute value of 100 μV at any electrode except EOGs were discarded. Four conditions of deviant concrete character, standard concrete character, deviant abstract character and standard abstract character were averaged for further analysis. In the averaging procedure, the first three epochs in each block and stimulus events preceded by a colour fixation cross or by a button press were rejected. In this data processing procedure, data from four participants were discarded due to a limited number of usable segments (< 50 % of all segments) in one of the four conditions, or low accuracy rate in the behavioural distraction task (< 50 %), before proceeding to further statistical analysis.

Statistical analysis of the ERP data

Choice of electrode sites and analysis time intervals were made with reference to previous literature on the semantic concreteness effect (West & Holcomb, 2000; Zhang et al., 2006) and on semantic MMN studies (Pulvermüller, Assadollahi, & Elbert, 2001; Shtyrov et al., 2004). See Figure 4.15 for clusters of electrodes. Midline and lateral site ERPs, quantified in respective areas by averaging the amplitudes of the electrodes included, were analysed in two separate ANOVAs of stimulus Type (deviant and standard), Condition (concrete and abstract character) and topographical factors. See Figure 4.16 for the ERPs of deviants and standards in the two conditions of concrete and abstract characters. For the midline analysis, the topographical factor was Region including frontal (Fz, FC1, FC2), central (Cz, CP1, CP2) and parietal (Pz, P3, P4) areas. For the lateral analysis, the topographical factors included Hemisphere (left and right) and Electrode-site: frontal (F7/8), temporal (T7/8), parietal (P7/8), temporo-parietal (TP9/10) and occipital (O1/2) sites. Time intervals of 180-230 ms, 250-310 ms, 310-400 ms and 400-450 ms were selected for analysis. Then, to explore any concreteness effects on the vMMN, difference deflections were created by comparing deviant and standard ERPs for both concrete and abstract words (i.e., concrete word deviants vs. concrete word standards; abstract word deviants vs. abstract word standards) (Figure 4.17). Here ANOVAs of Condition (concrete and abstract difference ERPs) and topographical factors were carried out also separately for midline and lateral sites. The same topographical factors as with the above analyses on semantic vMMN effect were adopted. Analysis time windows were selected with reference to the above-mentioned windows. In all of the analyses, Greenhouse-Geisser correction of the degrees of freedom was applied and the corrected p values were reported, where appropriate.

Time-frequency analysis

To further uncover the oscillatory underpinnings of the vMMN responses, time-frequency analysis of the EEG data was carried out also using Brain Vision Analyzer (Brain Products GmbH, Munich, Germany). Following the above-mentioned artifact rejection step in the EEG data processing, the four experimental conditions of standard and deviant abstract and concrete characters were segmented with a baseline of 400 ms before the onset of stimuli. Here, the number of the segments of standards was matched with that of deviants by selecting the standard stimuli preceding the deviant for analysis. This way, the potential influence of the number of the to-be-analysed segments on computing ERSPs and PLFs can be removed. Morlet wavelet transform was then applied to the segments with a frequency range from 1 to 40 Hz and with a logarithmic frequency step of 40. In order to achieve a balance of time and frequency resolution (Tallon-Baudry, 2004), the Morlet parameter was set to 5. ERSPs that include both phase-locked and non-phase-locked oscillations were computed by averaging the absolute values of the wavelet transforms of segments, with a baseline correction based on the prestimulus interval from -400 ms to -200 ms (Figure 4.18). In calculating PLFs, the wavelet coefficients instead of spectral powers of the wavelet transform were measured first. PLFs were then computed and rectified before data extraction for statistical analysis (Figure 4.19).

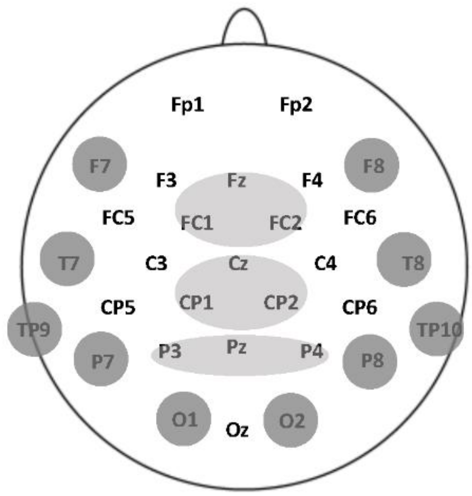


Figure 4.15 The clusters of electrodes. Frontal, central and parietal clusters are marked in light grey in the middle area. The other ten electrodes on the both sides in dark grey correspond to frontal, temporal, parietal, temporo-parietal, and occipital sites.

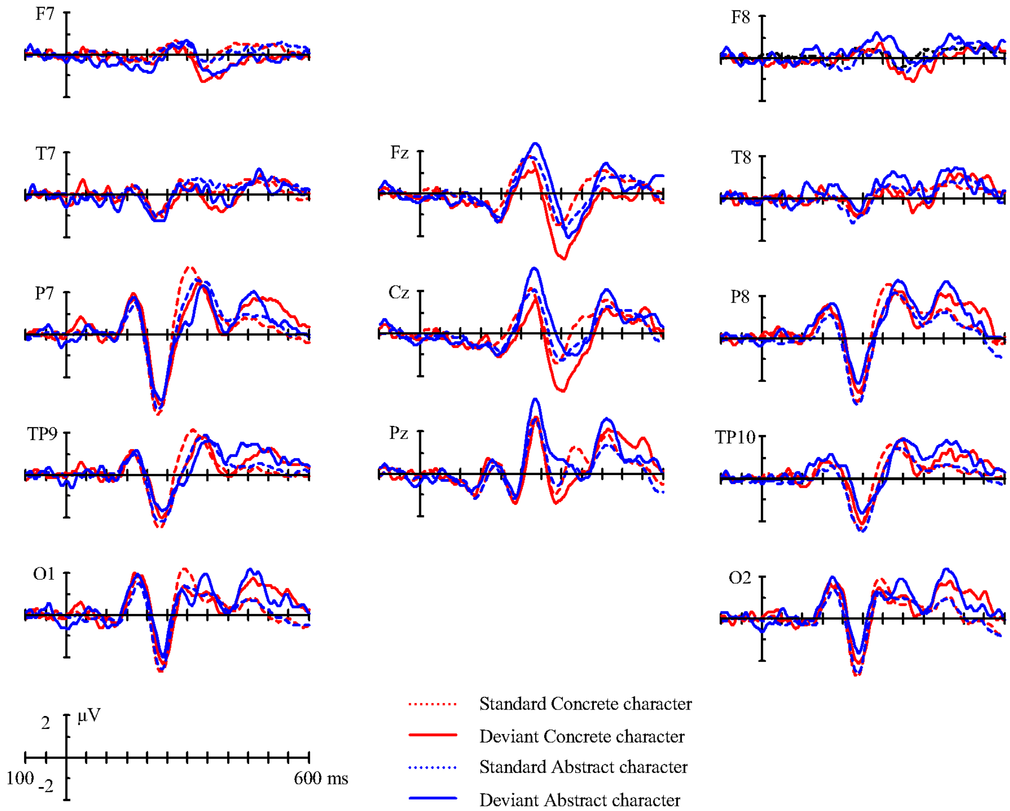


Figure 4.16. Comparison of deviant and standard stimuli. ERP waveforms for deviant (red solid) and standard (red dotted) concrete character conditions and for deviant (blue solid) and standard (blue dotted) abstract character conditions at midline electrodes Fz, Cz and Pz and side electrodes F7/8, T7/8, P7/8, TP7/8, and O1/2. Negativity is plotted downward.

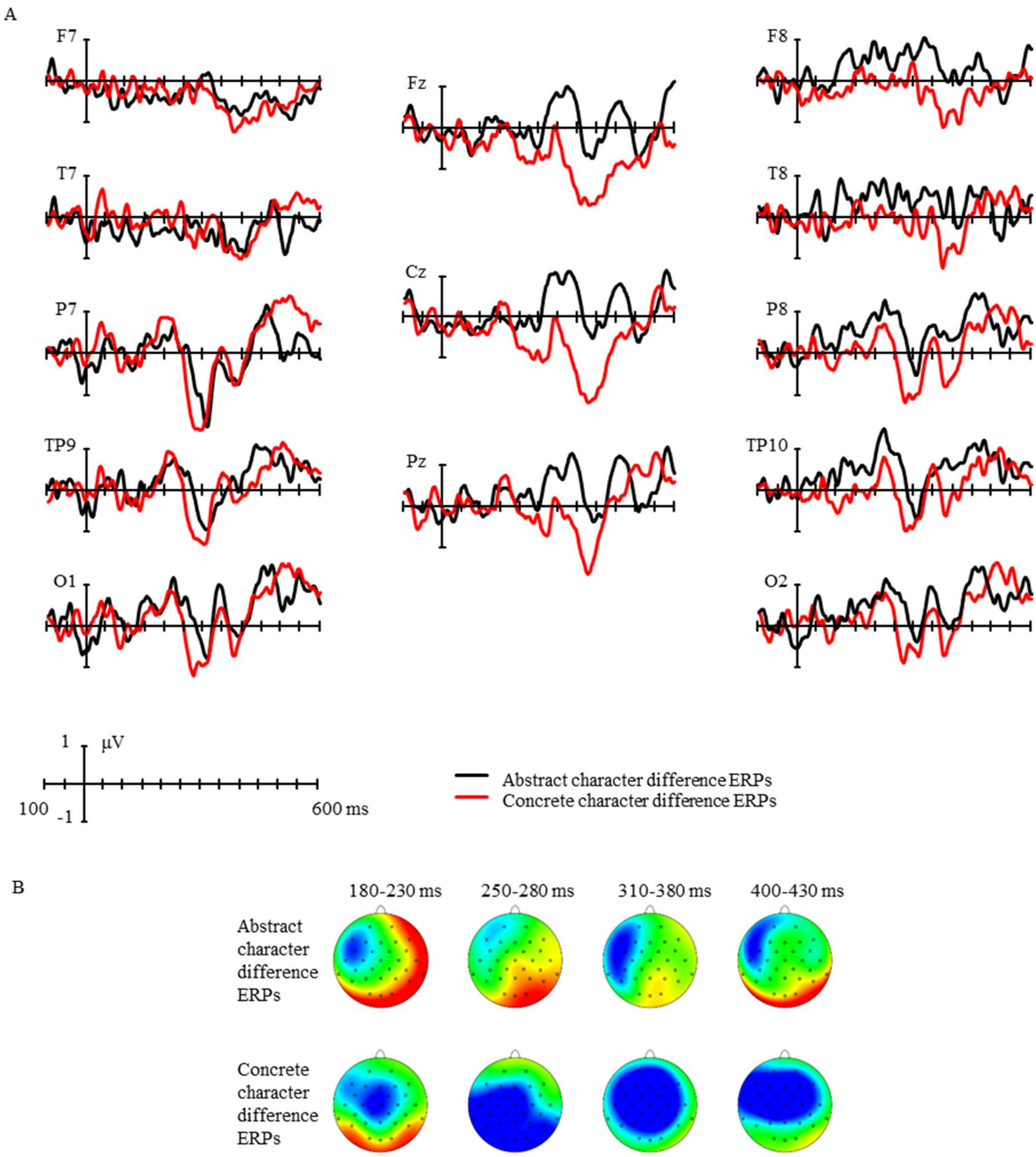


Figure 4.17 Comparison of Concrete and Abstract character deviant-minus-standard difference ERPs. Difference ERPs for concrete (red) and abstract (black) character conditions (A) and their corresponding topographical maps at four time intervals (B). Negativity is plotted downward.

4.5.2 Results

Behavioural performance

Paired samples t-test yielded no difference between the two blocks in terms of reaction times in response to the central fixation colour changes, in the block with abstract standards (572 ms) and in the other block with concrete standards (581 ms), $t(20) = -1.32$, $p > 0.1$.

In terms of accuracy, paired samples t-test suggested slightly higher accuracy rate in the block with concrete standards (93.2 %) than in the other block with abstract standards (90.2 %), $t(20) = -2.09$, $p < 0.05$.

Comparisons of deviant and standard ERPs

180-230 ms. In the lateral analysis, ANOVA yielded an interaction of Type, Hemisphere and Electrode-site, $F(4, 80) = 4.48$, $p < 0.01$, partial $\eta^2 = 0.18$. Post hoc analysis suggested that deviants were more negative than standards at the left frontal site (F7, deviant vs. standard, -0.49 vs. -0.13 μV, $p = 0.01$). ANOVA also yielded a main effect of Hemisphere, $F(1, 20) = 5.10$, $p < 0.05$, partial $\eta^2 = 0.20$. Post hoc analysis suggested larger negativity in the left than the right hemisphere, -0.67 vs. -0.21 μV. In the midline analysis, ANOVA yielded an interaction of Type and Region, $F(3, 60) = 9.67$, $p < 0.001$, partial $\eta^2 = 0.33$. Post hoc analysis, however, did not find any evidence of more negativity in deviants than in standards.

250-310 ms. In the lateral analysis, ANOVA yielded an interaction of Type and Hemisphere, $F(1, 20) = 7.75$, $p < 0.05$, partial $\eta^2 = 0.28$. Post hoc analysis suggested that deviants were more negative than standards in the left hemisphere, 0.14 vs. 0.69 μV, $p < 0.05$, while deviants did not differ from standards in the right hemisphere, $p > 0.1$. ANOVA also yielded an interaction of Type and Electrode-site, $F(4, 80) = 5.21$, $p < 0.05$, partial $\eta^2 = 0.21$. Post hoc analysis suggested the Type effect (i.e., vMMN) mainly focused on the parietal and temporo-parietal sites, ps < 0.05. In the midline analysis, there were no reliable effects.

310-400 ms. In the lateral analysis, ANOVA yielded an interaction of Type, Condition and Hemisphere, $F(1, 20) = 10.77$, $p < 0.01$, partial $\eta^2 = 0.35$. Post hoc analysis, however, indicated there was no difference between deviants and standards for either concrete or abstract characters. In the midline analysis, ANOVA yielded an interaction of Type and Condition, $F(1, 20) = 4.21$, $p = 0.05$, partial $\eta^2 = 0.17$. Post hoc analysis suggested that deviants were more negative than standards for concrete characters (-1.16 vs. -0.10 μV, $p < 0.05$) while there was no difference between deviants and standards for abstract characters ($p > 0.1$). There was also an interaction of Type and Region, $F(2, 40) = 4.33$, $p < 0.05$, partial $\eta^2 = 0.18$. Post hoc analysis suggested more negativity elicited by deviants than by standards in the frontal area.

400-450 ms. In the lateral analysis, ANOVA yielded an interaction of Type and Electrode-site, $F(4, 80) = 11.23$, $p < 0.001$, partial $\eta^2 = 0.36$. Post hoc analysis suggested more negativity for deviants than standards in the frontal sites, -0.14 vs. 0.29 μV. In the midline analysis, ANOVA yielded an interaction of Type and Region, $F(3, 60) = 10.13$, $p < 0.001$, partial $\eta^2 = 0.38$. Post hoc analysis suggested a marginally significant difference between deviant and standard characters, -0.17 vs. 0.42 μV, $p = 0.067$.

Concreteness effect on the difference ERPs

180-230 ms. In lateral analysis, ANOVA yielded an interaction of Condition and Hemisphere, $F(1, 20) = 7.14$, $p < 0.05$, partial $\eta^2 = 0.26$. Post hoc analysis, however, did not show a difference between the abstract and concrete conditions in either hemisphere, ps > 0.1. The difference ERPs for abstract characters was left-lateralised, 0.19 vs. 0.87 μV, $p < 0.05$. In the midline analysis, no reliable effects were observed, $F < 1$.

250-280 ms. In the lateral analysis, ANOVA yielded a main effect of Condition, $F(1, 20) = 4.73$, $p < 0.05$, partial $\eta^2 = 0.19$. Post hoc analysis revealed more negative difference ERPs to concrete than to abstract characters, -0.59 vs, 0.34 μV. ANOVA also yielded a main effect of Hemisphere, $F(1, 20) = 6.69$, $p < 0.05$, partial $\eta^2 = 0.25$. Post hoc analysis suggested that the negativity was distributed in the left more than the right hemisphere, -0.38 vs. 0.13 μV. In the midline analysis, ANOVA yielded a main effect of Condition, $F(1, 20) = 5.26$, $p < 0.05$, partial $\eta^2 = 0.18$. Post hoc analysis indicated more negativity in the difference ERPs of concrete than abstract characters, -0.75 vs. 0.52 μV.

310-380 ms. In the lateral analysis, ANOVA revealed an interaction of Condition and Hemisphere, $F(1, 20) = 11.60$, $p < 0.01$, partial $\eta^2 = 0.37$. Post hoc analysis showed that for abstract characters, the negativity was left-lateralised, -0.27 vs. 0.50 μV, $p < 0.01$ while there was no hemispheric difference for concrete characters, -0.28 vs. -0.20 μV, $p > 0.1$. In the midline areas, ANOVA yielded a main effect of Condition, $F(1, 20) = 4.98$, $p < 0.05$, partial $\eta^2 = 0.20$. Post hoc analysis showed that more negativity was elicited by concrete than abstract characters, -0.97 vs. 0.52 μV.

400-430 ms. In the lateral analysis, no reliable effects were observed, Fs < 1. In the midline analysis, ANOVA yielded a marginally significant interaction of Condition and Region, $F(3, 60) = 2.93$, $p = 0.082$, partial $\eta^2 = 0.13$. Post hoc analysis suggested a marginally significant difference between the difference ERPs of concrete and abstract characters at frontal area, -1.5 vs. -0.12 μV, $p = 0.086$.

Time-frequency results

Event-Related Spectral Power, ERSP

100-200 ms. A prominent overall power increase, greatest at 11 Hz, was observed at temporal-parietal, parietal and occipital areas in both standard and deviant conditions. In the lateral analysis, ANOVA revealed an interaction between Hemisphere and Electrode-site, $F(4,80) = 4.04$, $p < 0.05$, partial $\eta^2 = 0.17$. Post hoc analysis showed more power increase in the left than the right hemisphere of temporal, parietal and occipital sites. The interaction between Type and Condition reached marginal significance, $F(1,20) = 4.33$, $p = 0.051$, partial $\eta^2 = 0.18$. Post hoc analysis however, did not show a difference between deviant and standard stimuli. In the midline analysis, no significant effects were observed between deviants and standards, $p > 0.05$.

200-300 ms. Standard and deviant stimuli elicited an increase in overall spectral power, greatest at 6 Hz. In the lateral analysis, ANOVA showed an interaction between Condition and Electrode-site, $F(4,80) = 10.41$, $p = 0.001$, partial $\eta^2 = 0.33$. Post hoc analysis revealed that concrete characters produced more power increase than abstract characters at parietal and occipital sites, 5.16 vs. 3.83 μV^2, 3.03 vs. 1.40 μV^2, ps < 0.05. In the midline analysis, ANOVA showed a main effect of Type, with deviant stimuli producing larger power increase than standard stimuli, $F(1,20) = 9.81$, $p < 0.01$, partial $\eta^2 = 0.33$, 3.64 vs. 1.90 μV^2.

ANOVA also indicated an interaction of Condition and Region, $F(2,40) = 7.42$, $p < 0.01$, partial $\eta^2 = 0.27$. Post hoc analysis however, did not show any difference between concrete and abstract characters.

300-450 ms. Both standard and deviant stimuli elicited a decrease in overall spectral power, greatest at 12 Hz (Figure 4.18). In the lateral analysis, ANOVA revealed an interaction between Type and Condition, $F(1,20) = 4.80$, $p < 0.05$, partial $\eta^2 = 0.19$. Post hoc analysis indicated that the difference between deviants and standards of concrete characters reached marginal significance, $p = 0.062$, -2.58 vs. -0.95 μV^2, while there was no difference between deviant and standard abstract characters, -2.37 vs. -3.28, $p > 0.1$. The interaction of Condition and Electrode-site reached significance, $F(4,80) = 4.16$, $p < 0.01$, partial $\eta^2 = 0.17$. Post hoc analysis showed that abstract characters had stronger power decrease than concrete characters in temporal-parietal (-2.01 vs. -0.97 μV^2, $p < 0.05$), parietal (-5.57 vs. -3.75 μV^2, $p < 0.05$), and occipital (-6.36 vs. -4.18 μV^2, $p = 0.058$) sites. In the midline analysis, no significant effects between standards and deviants were observed.

Phase locking factor, PLF

Both standard and deviant stimuli elicited an increase in PLF, strongest at 4-8 Hz, between 150 and 450 ms (Figure 4.19). The increased PLF was focused on the temporal and parietal areas. ANOVAs were separately carried out in lateral and midline sites in the window of 200-450 ms.

In the lateral analysis, ANOVA revealed an interaction between Type and Hemisphere, $F(1,20) = 5.92$, $p < 0.05$, partial $\eta^2 = 0.23$. Post hoc analysis found that deviants elicited higher PLF in the left hemisphere than in the right hemisphere, 0.29 vs. 0.26 μV. The interaction between Type and Electrode site also reached significance, $F(4,80) = 5.87$, $p = 0.01$, partial $\eta^2 = 0.23$. Post hoc analysis showed that deviants elicited higher PLF in frontal and temporal sites, 0.24 vs. 0.19 μV, 0.22 vs. 0.18 μV, $ps < 0.001$. ANOVA also revealed an interaction between Condition and Electrode site, $F(4,80) = 5.22$, $p < 0.01$, partial $\eta^2 = 0.21$. Post hoc analysis showed that concrete characters had higher PLF than abstract characters at temporal, temporal-parietal, parietal and occipital sites, 0.21 vs. 0.19 μV, $p = 0.054$, 0.33 vs. 0.30 μV, $p < 0.01$, 0.36 vs. 0.32 μV, $p < 0.01$, 0.29 vs. 0.27 μV, $p < 0.05$.

In the midline analysis, ANOVA revealed a main effect of Type, $F(1,20) = 12.27$, $p < 0.01$, partial $\eta^2 = 0.38$. Post hoc analysis showed that deviants elicited larger PLF than standards, 0.27 vs. 0.24 μV. No other effects reached significance.

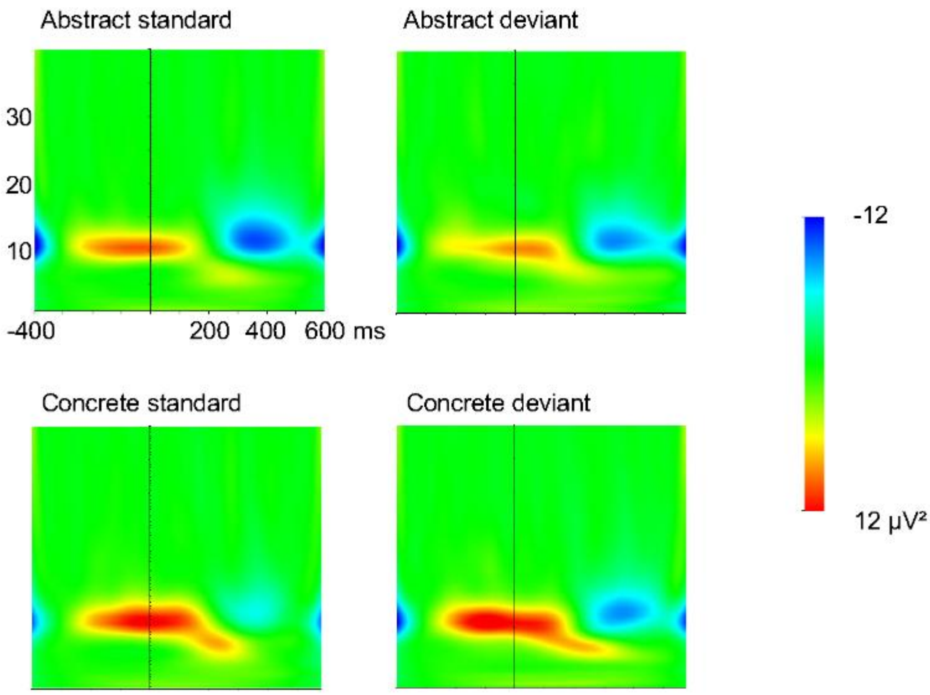


Figure 4.18 ERSPs of deviant and standard characters. Upper panel: abstract standard and deviant characters; lower panel: concrete standard and deviant characters. The plots are based on electrode P7.

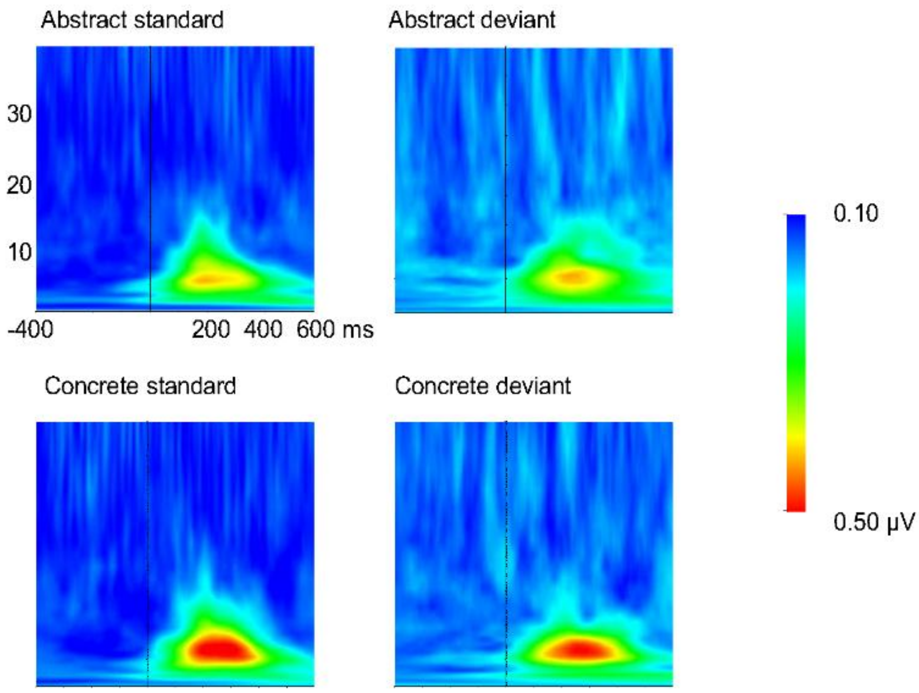


Figure 4.19 PLFs of deviant and standard characters. Upper panel: abstract standard and deviant characters; lower panel: concrete standard and deviant characters. The plots are based on electrode P7.

4.5.3 Discussion

The current experiment investigated early and automatic processing of semantics in Chinese character reading. Concrete and abstract characters were presented perifoveally and participants were asked to carry out a non-linguistic distraction task presented in the middle of the screen. An oddball paradigm was used, where concrete and abstract characters acted as deviants and standards in one block and were swapped in the other block. Deviants elicited larger negative amplitudes than standards intermittently across a long time interval of 180-450 ms. Importantly, concrete characters elicited more negative difference ERPs/vMMN than abstract characters at the intervals of 250-280 ms and 310-380 ms. According to time-frequency analysis of the electrophysiological data, both standard and deviant characters elicited similar alpha power increase at the parietal and occipital sites from the stimulus onset to around 200 ms. This early overall spectral power increase was dominant in the left hemisphere. In the interval of 200-300 ms, deviants elicited larger theta power increase peaking around 6 Hz in the middle areas. Concrete characters elicited a larger theta power increase than abstract characters in the lateral sites. In the third interval of 300-450 ms, deviant stimuli elicited larger alpha power decrease than standard stimuli in the lateral sites. Abstract characters elicited larger alpha power decrease than concrete characters in the lateral areas except frontal and temporal sites. In terms of PLF, both deviant and standard stimuli yielded a PLF increase in the theta range, peaking at 4-8 Hz, across a long latency between 150 to 450 ms. In the interval of 200-450 ms, deviants elicited larger PLF than standards in frontal and temporal sites and midline areas; and concrete characters yielded larger PLF than concrete characters mainly in the temporal, parietal and occipital sties. These results are discussed below.

ERP responses

In this experiment, characters were contrasted in terms of their concreteness, but matched in visual complexity (in terms of stroke numbers), phonetic regularity, lexical frequency and emotionality (in terms of valence and arousal). Therefore, the ERP difference between deviant and standard stimuli is best attributed to the concreteness contrast. In other words, the vMMN was elicited by rapid and automatic detection of semantic change, represented by deviants and standards of the two different semantic categories in terms of their degree of concreteness. This finding extends previous investigations of non-linguistic object feature detection in vMMN studies (for a recent review, see Kremláček et al., 2016) to the high-order semantic level.

In the current experiment, the semantic change was detected before 200 ms and at later intervals until around 450 ms. In terms of early timing, this finding agrees with previous studies on semantic processing in the auditory MMN field. As all the participants in the current experiment are well-educated native Chinese college students, they presumably have developed strong mental representations of the stimuli tested here, or in other words, long-term memory representations of the linguistic items, as suggested and confirmed in previous MMN studies with spoken word stimuli (Pulvermüller et al., 2005; Shtyrov, 2010; Shtyrov et al., 2004). These studies on auditory semantic processing are based on the semantic somatotopy hypothesis, which suggests that the semantic/motor features of action verbs can be somatotopically mapped in the frontal motor cortex. Words which characterise actions performed with the face or legs, for instance, "lick" or "kick", are found to activate corresponding motor and premotor cortical sites (Hauk, Johnsrude, & Pulvermüller, 2004; Hauk & Pulvermüller, 2004b). Using MEG, Pulvermüller et al. (2005) investigated the spatio-temporal patterns of the leg-related and face-related spoken action words in terms of their MMNm responses. The authors found that shortly after the acoustic input permitting unique lexical identification ("word recognition point"), face-related stimuli had more activation in inferior frontocentral areas than leg-related stimuli and leg-related stimuli had more activation at superior central areas around 150-200 ms. These results provide evidence for early and automatic semantic processing.

The early semantic processing in the current experiment may also be attributed to the unique features of Chinese language, which is characterised by a direct orthography-meaning correspondence with a relatively weak mediating role of phonology in accessing word meaning (Chen & Shu, 2001; Wang, 2011; Zhang, Xiao, & Weng, 2012, but see Perfetti & Tan, 1998). Indeed, there is no direct grapheme-phoneme correspondence in the writing system of Chinese, in contrast to alphabetic languages such as English and Spanish where letters have more or less clear phonemic representations. Of particular relevance to the current study, Zhang et al. (2006) discussed semantic processing of Chinese words in a LDT task. They reported more negative N400 to concrete than to abstract noun words at 300-500 ms, an effect which spread across the scalp and was largest at left anterior sites. Interestingly, in contrast to similar studies with words in alphabetic languages (e.g., Holcomb et al., 1999), the concreteness effect was also observed at an earlier interval of 200-300 ms, which might be attributed to the semantic characteristics of Chinese words. Therefore, the characteristics of Chinese in terms of semantic activation may play a role in the early semantic processing represented by a vMMN effect around 200 ms.

In the present experiment, it is seen that semantic processing can be achieved early even when attention is not directed to the critical stimuli. Among the few studies on semantic processing using a vMMN design, recently Fujimura and Okanoya (2013) explored automatic detection of the emotional connotations of Kanji words. Negative or positive deviants and neutral standards, represented by Japanese Kanji single-character words in black, were displayed in the middle of the screen for 200 ms. Participants' task was to detect targets which were the same Kanji words as the standards, albeit in a different colour (grey vs. black). They described an early enhanced vMMN to a strongly emotional deviant in comparison with neutral standards, at an early latency of 200-300 ms, which is also consistent with the current findings of early semantic processing. In their study, however, the targets were also members of the vMMN-eliciting emotion words. In addition, all the stimuli were centrally presented, despite the fact that emotional connotation is particularly attention-capturing due to its relevance with survival (Lang, Bradley, & Cuthbert, 1997). Arguably, this method of distraction may not be stringent enough to avoid the attentional grabbing of the vMMN-eliciting critical stimuli. Thus the “automatic” nature of these findings may be questionable. In the current study, with an improved design of perifoveal presentation of critical stimuli in an identity oddball paradigm, vMMN was also observed, thus providing more compelling evidence of automatic semantic change detection.

By comparing the difference ERPs of concrete and abstract characters, it was observed that concrete characters elicited larger vMMN than abstract characters. Given the identity oddball paradigm in the present study, the concrete character advantage can be best attributed to the concreteness disparity between the concrete and abstract characters, which were matched in other dimensions such as visual complexity and emotional valence. The advantage was shown as an enhanced vMMN displayed both in lateral and midline analysis around 250-380 ms. This finding agrees well with previous literature on the processing differences between concrete and abstract words. Though employing different tasks, such as LDT, imageability ratings and concreteness judgment, previous studies seem to yield fairly consistent findings that concrete words elicit more negative N400, with a wide topographical distribution largest at posterior and extending to frontal areas (Holcomb et al., 1999; Huang et al., 2010; Kanske & Kotz, 2007; Tsai et al., 2009; West & Holcomb, 2000; Zhang et al., 2006). For example, in an LDT task with English words, Kounios and Holcomb (1994) found that concrete words elicited larger N400 amplitudes than abstract words in the latency of 300-500 ms, with a topographical distribution all across the scalp. The authors argued that more semantic information in memory for concrete words than for abstract words was activated, leading to the N400 enhancement. Similarly, the more and possibly stronger semantic associations of concrete characters may be reflected as larger vMMN. In terms of topographic distribution, in the current study, more vMMN was found for concrete characters in both middle and lateral analyses. Importantly, around 310-380 ms, the right hemispheric involvement in the concrete characters was observed in contrast to the left-lateralisation of the difference ERPs of the abstract characters. These results run against the context availability theory (Schwanenflugel & Shoben, 1983), according to which, there should have been no difference between abstract and concrete characters in the current study, since both of them were presented in the same unsupportive, attention-deprived context. Instead, this finding is consistent with the extended dual-coding theory, which predicts more involvement of non-verbal image-based representation in the right hemisphere and more verbal representations in the left hemisphere for concrete as opposed to abstract words (Jessen et al., 2000; Levy-Drori & Henik, 2006; Paivio, 1991).

Oscillatory characteristics

Initially similar alpha power increase was found for both deviant and standard stimuli, which may reflect involuntary attentional capture by the unattended stimuli in the peripheral area (Jensen, Bonnefond, & VanRullen, 2012). Though participants were instructed not to pay active attention to these stimuli, they must be aware of the visual input in an otherwise blank area. The leftward topographical distribution of the spectral power in the early window before 200 ms may show a hint of language processing given the linguistic specificity of the visual input in the current experiment.

After the initial window, both deviant and standard stimuli elicited overall spectral power increase in the theta range. This finding is in line with previous MMN studies in both auditory and visual modalities using elementary non-linguistic stimuli (Hsiao, Cheng, Liao, & Lin, 2010; Hsiao, Wu, Ho, & Lin, 2009; Ko et al., 2012; Stothart & Kazanina, 2013), documenting the role of the theta band oscillations in deviant detection regardless of the mode of presentation. For example, in a vMMN study on frame colour change detection, Stothart and Kazanina (2013) reported that similar theta power increase was yielded by deviant and standard stimuli alike before 200 ms. In the current experiment, while on the lateral sites the theta power between deviants and standards did not differ, deviants elicited larger theta power increase than standards in the middle sites. This difference between the two types of stimuli has seldom been found in the above-mentioned MMN studies. The reason may lie in the special stimulus category of language in contrast to the basic-level auditory or visual features often targeted in those studies. Since deviant and standard characters are different only in the semantic concreteness dimension, the theta power difference may reflect such an early semantic change detection. Consistent with this viewpoint, previous studies have reported that theta band spectral power increase can suggest lexical-semantic information retrieval (Bastiaansen et al., 2008; Bastiaansen et al., 2005). In fact, in the parietal and occipital sites, the current experiment also found enhanced theta power elicited by concrete characters comparing with abstract characters, adding further evidence for the relevance of theta power to semantic processing.

In the following window of 300-450 ms, all the stimuli elicited alpha power decrease. Alpha power decrease has been reported in previous vMMN studies which focused on elementary visual feature detection (Stothart & Kazanina, 2013; Tugin et al., 2016). It has been suggested that while alpha power increase reflects task-related inhibition within a cortical area (Jensen, Gips, Bergmann, & Bonnefond, 2014; Palva & Palva, 2007), a decrease in the oscillatory amplitude suggests active neuronal processing (Pfurtscheller & Da Silva, 1999; Thut, Miniussi, & Gross, 2012). It has been demonstrated in a large array of studies that alpha band decrease is typically associated with the enhanced attentional demands of processing (Bastiaansen, Böcker, & Brunia, 2002; Klimesch, 1999; Stothart & Kazanina, 2013; Wang & Bastiaansen, 2014). Therefore, the alpha power decrease detected here might indicate that both deviants and standards are undergoing increased processing after the initial early-phase semantic processing indicated by the theta power increase. Whereas Stothart and Kazanina (2013) and Tugin et al. (2016) reported a larger alpha reduction for deviants than standards, in the current study there is no reliable difference in alpha reduction between deviants and standards for either concrete or abstract characters. One possible reason for this discrepancy might lie in the stimuli used in different studies. Though a common non-attend paradigm was used in these authors' studies and the current ones, higher-order linguistic items are relatively more difficult to process as deviants and standards, and thus demand more attentional resources than basic visual features such as colour bars (Stothart & Kazanina, 2013) and moving dots (Tugin et al., 2016). Interestingly, when abstract and concrete characters are compared, the former elicited larger reduction in alpha band than the latter. This aligns well with previous studies showing that alpha power decrease, especially in its upper band (i.e., above 11 Hz) suggests semantic information retrieval, which demands enhanced attentional resources (Klimesch, Doppelmayr, Pachinger, & Russegger, 1997; Pérez, Molinaro, Mancini, Barraza, & Carreiras, 2012). In line with this viewpoint, abstract characters are considered to have fewer underlying semantic nodes in comparison with concrete characters, therefore making them less likely to support involuntary semantic retrieval in attention-deprived experimental conditions. An alternative explanation for the larger alpha power decrease by abstract characters consists in the greater attentional demands for abstract character processing without involving semantic retrieval (Bastiaansen and Hagoort, 2006). However, due to the closely-related association between attentional processing and semantic retrieval (Li & Ren, 2012), it is difficult to dissociate these two possibilities. The difference in alpha power decrease between abstract and concrete characters may reflect a combination of both attentional demands and semantic processing. Further studies are needed to investigate the nature of alpha power decrease in response to factors of attention and semantics.

Relationship between ERPs and TF representations

While the TF data adds a new perspective to exploration of the semantic change detection mechanism, the temporal resolution of spectral power analysis is not as precise as that of ERP measurement, which means the onset and offset of the overall spectral power effects should be better taken as a rough estimation of relevant underlying neurophysiological activity (Clochon, Fontbonne, Lebrun, & Etévenon, 1996). Nevertheless, the spectral power latencies of theta and alpha bands largely overlap with the ERP effects in the current experiment. The initial theta power increase may correspond with the early automatic change detection as indexed by the early stage vMMN effects before 300 ms. The larger vMMN effect of concrete in comparison with abstract characters in the later windows may be similar in timing with the alpha power decrease effects for concrete and abstract characters. However, it is the abstract characters that yielded larger alpha power decrease compared to the concrete characters, which is different from findings with traditional ERP analysis, where the opposite has been found, i.e., concrete characters elicited larger vMMN than abstract characters. This points towards the notion that time-frequency analysis of the event-related EEG responses may characterise different neurophysiological mechanisms from traditional ERP analysis. It remains a matter of debate as to how ERPs and TF representations relate to each other (Hanslmayr et al., 2007; Mathewson, Gratton, Fabiani, Beck, & Ro, 2009; Mazaheri & Jensen, 2006), making it difficult to make a direct comparison between the ERP and TF representation findings. This being said, a more complete view of the neurodynamics involved in semantic change detection has been achieved with a combination of the two analyses of the EEG data.

Phase synchronisation

Different from spectral power analysis, phase locking analysis characterises the synchronisation between spatially disparate areas into transitory neural networks, thus providing a unique tool to probe into neuronal dynamics. In the current study, the difference between the theta phase locking for deviant and standard stimuli coincided with the vMMN effect in the visual evoked potentials in the interval between 200 ms and 450 ms. Therefore, theta phase locking is suggested to play a role in the vMMN effects. This result agrees well with a previous vMMN study on visual colour bar detection (Stothart & Kazanina, 2013) as well as a series of auditory MMN studies (Bishop & Hardiman, 2010; Fuentemilla et al., 2008; Hsiao et al., 2009; Ko et al., 2012), indicating that the common role of theta phase locking in generating (v)MMN is independent of stimulus type and presentation modality. While these studies feature larger theta phase locking for deviant than standard stimuli in the right hemisphere, a clear left-lateralisation was found in the current experiment. This topographical difference may be attributed to linguistic processing in contrast to the basic feature perception seen in those previous studies. Similarly, larger phase locking for deviants than standards was found in frontal, temporal and middle sites, which is consistent with the topographies of vMMN effects, adding further support for the role of phase locking in language-related processing indexed by vMMNs. In addition, concrete characters elicited higher theta phase locking than abstract characters, which is also in line with the larger vMMN for concrete than abstract characters in the ERP domain. Such a pattern may be attributable to the denser semantic links underlying concrete characters, which neurophysiologically are represented as stronger functional connections in the lateral sites such as the temporal-parietal and parietal ones. Therefore, the concreteness effect in the time domain is supported from the perspective of theta phase locking in the frequency domain.

4.5.4 Conclusion

By comparing well-matched concrete and abstract Chinese characters in terms of their vMMN amplitude, it was found that both types of characters can yield vMMNs and that concrete characters elicit larger vMMN than abstract characters. Corroborating these results in the time domain, deviants were found to elicit larger theta band power increase in an interval before 300 ms and stronger theta phase synchrony from 200 to 450 ms. In addition, concrete characters elicited larger theta power increase and phase locking than abstract characters, supporting a concreteness effect also in the time frequency analyses. Interestingly, abstract characters yielded larger alpha power decrease in later window after 300 ms, which is attributed to more difficulty in processing abstract characters in an attention-limited condition. Based on these results, it can be concluded that semantic information of Chinese characters is processed early and automatically. A combination of traditional ERP measures and time-frequency analysis has enabled a more complete picture of automatic semantic processing. (Note on statistical analysis in the current experiment. An improvement to the study would be to carry out a different topographic analysis with laterality as a factor instead of doing separate lateral and midline analysis. I would like to thank my external examiner for this suggestion).

4.6 Experiment 6: Extending the findings to Spanish, an alphabetic language

It has been seen in the previous experiments of this project that lexical-semantic changes in Chinese can elicit vMMNs, suggesting early and automatic language processing. In contrast, Shtyrov and collaborators (2013) did not report a difference between real and pseudo- Russian words in terms of vMMN responses. Since similar oddball paradigms were applied in these two studies, the discrepant pattern of results might be related to the experimental stimuli constructed in different languages. Since there have been few studies investigating language-related vMMN effects, it is pertinent to explore this issue further, using the same paradigm as in Experiment 1 but with a different language (in this case , Spanish) in which to construct the critical stimuli. In addition, it was found in Experiment 2 that, similar to previous vMMN studies with elementary non-linguistic stimuli (Czigler et al., 2002; Takács et al., 2013), the magnitude of deviance affects amplitudes of vMMN. Specifically, reduced deviance may lead to an absence of vMMN effect. Therefore, in the current experiment, relatively large deviance was designed. Specifically, the critical real, pseudo- and non- words constructed using Spanish letters were contrasted with a set of perceptually dissimilar symbols which were random combinations of Chinese and Korean strokes, instead of alphabetic letters. Therefore, six blocks were created: standard real-/pseudo-/non- words vs. deviant symbols and deviant real-/pseudo-/non- words vs. standard symbols.

Based on the results of Experiments 1 and 2, it was expected that firstly, vMMN may be elicited by the Spanish stimuli, indicated as the larger negativity for deviants compared with standards; secondly, larger vMMN might be elicited by real- than pseudo- and non- words.

4.6.1 Materials and methods

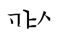
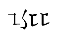
Participants

Twenty native Spanish college students were involved in the experiment for course credit, which was carried out in the Psycholinguistics Lab, University of La Laguna, Spain. Data from two participants was eliminated from the analysis, due to an excessive number of artifacts, resulting in a final sample of 18 people (including two males). Participants were similar in terms of age (20.5 ± 4.6, range: 17) to the Chinese college student participants in Experiment 1a. All of them reported no neurological or psychological disorders. All had normal or corrected-to-normal vision and were right-handed (Oldfield, 1971). Before the experiment, they gave their written informed consent. The experimental study was approved by the Research Ethics Committees of the University of La Laguna, Spain and that of the University of Nottingham Ningbo, China.

Materials

The critical stimuli included real, pseudo- and non- words in Spanish, as well as symbols. Each of the five real words was a four-letter long Consonant-Vowel-Consonant-Vowel (CVCV) structured noun, with relatively high frequency values (Mean log frequency, 2.05. Maximum, 2.40; Minimum, 1.68, according to the EsPal database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013). Real words were also rated high in terms of familiarity, concreteness and imaginability according to the database (Duchon et al., 2013) (mean rating for each of the three dimensions > 5.6 on a scale of 1-7). Pseudo-words were coined using eight CV bigrams of real words plus two new bigrams. Their status of pseudo-words was confirmed by the EsPal (Duchon et al., 2013). Non-words were all four-consonant letter sequences. The five tokens of symbols were made up of Chinese and Korean strokes. Care were taken to ensure all the stimuli were in similar size. Table 4.5 presents a full list of the stimuli.

Table 4.5 A list of real, pseudo-, non- words and symbols

Stimuli	**1**	**2**	**3**	**4**	**5**
Real word	luna	hora	hijo	nave	mesa
(Gloss)	*moon*	*hour*	*son*	*ship*	*table*
Pseudo-word	mejo	nahi	hina	hona	lura
Non-word	gcbd	jlsd	rpth	pnbt	cjlm
Symbols					

Procedure

This experiment used the same procedures as in Experiment 1 but with three differences. First, due to the spatial arrangement of letter sequence, the size of the stimuli in the current experiment was slightly longer horizontally but shorter vertically (100 × 60 in the current experiment vs. 75 × 75 in Experiment 1a, pixel^2). Second, unlike Experiment 1a with four blocks, here six blocks in total were included: Blocks 1-3, Standard Real/Pseudo-/Non- words vs. Deviant Symbols; Blocks 4-6, Standard Symbols vs. Deviant Real/Pseudo-/Non- words. Third, in order to control the total experiment time, the deviants and standards (60 vs. 360) in each block were fewer than those in Experiment 1a (90 vs. 540) while keeping the ratio between deviants and standards unchanged.

EEG recording and ERP analysis

EEG was registered using Brain Vision Recorder with a sampling rate of 500 Hz and a band-pass from 0.01-100 Hz. An EasyCap of 27 electrodes was used (Figure 4.20), which is slightly different from the cap in Experiment 1a (see Figure 4.2 A). To record VEOG and HEOG, two electrodes above and below the right eye and another two at the outer canthus of each eye were applied. All impedances (except EOGs below 10 kΩ) were maintained at or below 5 kΩ. The reference electrode was the left mastoid online and re-referenced to the algebraic mean of the activity at the left and right mastoids. Offline, the data were analysed in Brain Vision Analyzer with similar configurations as those indicated in previous experiments. The average number (and standard deviation, SD) of accepted segments for standard and deviant Real, Pseudo- and Non- words were 320 (29.0), 54 (5.1), 321 (28.9), 54 (6.0), 309 (39.3) and 54 (6.3), respectively.

Due to the electrode distribution difference from the cap used in Experiment 1, in this experiment Region was clustered as follows (See Figure 4.20 for the electrode map): frontal (F3/4, FC1/2, FC5/6), central (C3/4, CP1/2, CP5/6) and parietal (P3/4, P7/8, O1/2) areas and Hemisphere (left and right) for the analysis for the lateral areas and frontal (Fz), central (Cz) and parietal (Pz) for the analysis of the midline sites. Difference ERPs of Real/Pseudo-/Non-characters were defined as comparisons of deviants and standards of the same lexical types, for instance, the difference ERP of Real words was defined as deviant vs. standard Real words (Figure 4.21). The difference ERPs of the three critical types of stimuli suggested possible vMMN effects only after 350 ms in frontal and central areas (Figure 4.22). With reference to Experiment 1, six intervals of 120-160 ms, 160-200 ms, 200-250 ms, 330-370 ms, 370-420 ms and 480-540 ms were selected to identify any possible negativity in the comparison between deviants and standards. Difference ERPs of real, pseudo- and nonwords were also compared for intervals where evidence of vMMN was present. Where appropriate, Greenhouse-Geisser corrections for violations of sphericity were applied, and original degrees of freedom and corrected p values were reported.

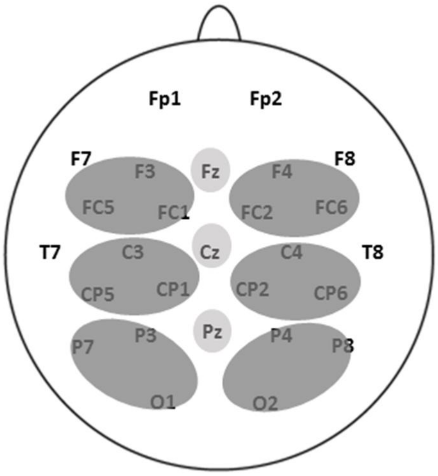


Figure 4.20 The clusters of electrodes.

4.6.2 Results

Behavioural results

Mean response times were 402 ms, 402 ms, 403 ms, 400 ms, 405 ms and 406 ms, corresponding to the standard and deviant Real, Pseudo- and Non- words. Accuracy rates for the six blocks were all above 98 %.

ERP results

As shown in Figure 4.21, the negativity of the difference ERPs seemed to appear only after 350 ms. Figure 4.22 shows the topographical maps of the difference ERPs of the three types of stimuli after 350 ms. The negativities were focused on frontal areas.

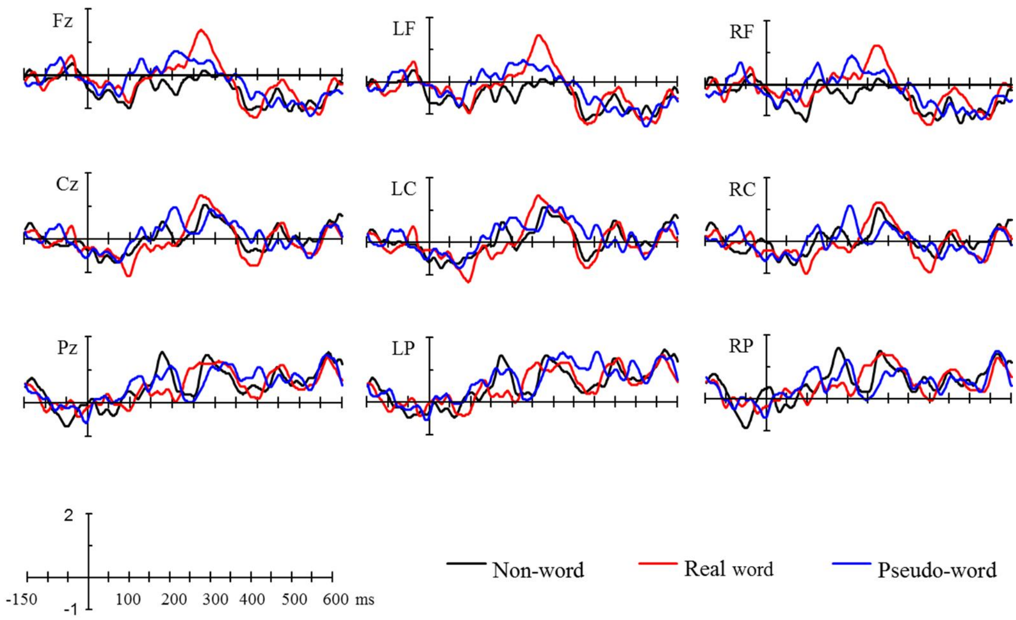


Figure 4.21 Difference ERPs of real, pseudo- and non- words at (left and right) frontal, central and parietal areas as well as in the midline sites. Negativity is plotted downward.

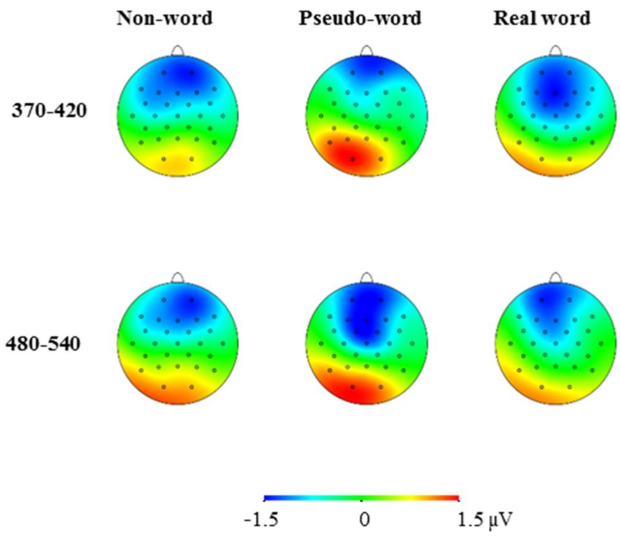


Figure 4.22 Topographical maps of the difference ERPs of the three types of stimuli at 370-420 ms and 480-540 ms.

Comparing the ERPs to deviants and standards

120-160 ms. ANOVA yielded interactions of Type and Region in both lateral and midline clusters, $F(2,34) = 5.12$, $p < 0.05$, partial $\eta^2 = 0.23$; $F(2,34) = 5.21$,

$p < 0.05$, partial $\eta^2 = 0.30$. However, post hoc analyses did not reveal any differences between deviants and standards in either lateral or midline clusters, $ps > 0.5$.

160-200 ms. ANOVA yielded interactions of Type, Lexicality and Region in both lateral and midline clusters, $F(4,68) = 5.07$, $p < 0.05$, partial $\eta^2 = 0.23$; $F(4,68) = 5.73$, $p < 0.01$, partial $\eta^2 = 0.25$. However, post hoc analyses did not reveal any differences between deviants and standards in either lateral or midline clusters, $ps > 0.5$.

200-250 ms. No significant effects were observed in this time window.

330-370 ms. ANOVA revealed interactions of Type and Region in both lateral and midline clusters, $F(2,34) = 6.94$, $p < 0.05$, partial $\eta^2 = 0.29$; $F(2,34) = 14.22$, $p < 0.001$, partial $\eta^2 = 0.46$. However, post hoc analyses did not reveal any differences between deviants and standards in either lateral or midline clusters, $ps > 0.5$.

370-420 ms. In lateral clusters, ANOVA yielded an interaction of Type and Region, $F(2,34) = 12.1$, $p < 0.01$, partial $\eta^2 = 0.42$. Post hoc analysis suggested more negativity in deviants than standards only in the frontal area, $p < 0.5$, deviant vs. standard, -2.05 vs. -1.15 μV, $p = 0.05$). No significant effects were observed in midline clusters.

480-540 ms. In lateral clusters, ANOVA yielded an interaction of Type, Region and Hemisphere, $F(2,34) = 6.18$, $p < 0.05$, partial $\eta^2 = 0.27$. Post hoc analysis suggested a difference between deviants and standards in the frontal area, at both left (-1.38 vs. -0.37) and right (-1.23 vs. -0.34) hemispheres. In midline clusters, ANOVA also revealed an interaction of Type and Region, $F(2,34) = 25.47$, p <

0.001, partial $\eta^2 = 0.60$. Post hoc analysis showed that deviants were more negative than standards at frontal (-1.77 vs. -0.42 μV, $p < 0.01$) and central (-1.58 vs. -0.67 μV, $p < 0.05$) sites.

4.6.3 Discussion

The present experiment investigated whether vMMN could be elicited by Spanish words and word-like stimuli and whether the results of Experiment 1 showing different vMMN effects for real and pseudo characters could be replicated in Spanish for real, pseudo and non-words contrasted with symbols. Contrary to what was expected, there was no evidence of early vMMN in the current experiment. In the later interval after 370 ms, vMMNs were observed, but there were no differences between the three stimulus types of real, pseudo- and non- words.

The absence of early vMMN effects might be attributed to the alphabetic nature of the Spanish stimuli. However, real, pseudo- and non- words in alphabetic Russian also elicit vMMNs at the interval of 100-260 ms, albeit with no differences in amplitude between different stimulus types (Shtyrov et al., 2013).

Physical difference in terms of item size between the Spanish words and Chinese characters as a potential explanatory factor can also be eliminated as their sizes were controlled to be similar. To explain the null result, therefore, it is tentatively suggested that the large magnitude of deviance between deviants and standards in the present experiment could be one of the potential factors. This could seem counter-intuitive as it is assumed that a large difference between deviant and standard stimuli may help promote detection of deviant changes, as supported in both MMN studies in auditory (Näätänen et al., 2007) and visual (Czigler et al., 2002; Czigler & Sulykos, 2010) modalities. However, in a previous experiment in the current project, when comparing real and pseudo-characters directly (Experiment 2), again no sign of vMMN was observed. In contrast, in Experiment 1, where real and pseudo-characters were contrasted with non-characters, an early vMMN was elicited by real characters (The different magnitudes of deviance in stimuli in Experiments 1, and 2 have been discussed in the report of Experiment 2, thus are not detailed here to avoid redundancy.). In Shtyrov et al. (2013), what was shared between the different experimental conditions was a delicate orthographic contrast between the Russian letters k and h, fixed in the final position of a three-letter stimulus. This relatively small contrast between deviants and standards, together with their tachistoscopic presentation, might affect participants' accurate discrimination of real and pseudo- words, thus resulting in no vMMN difference between them. In fact, though not directly studied in previous (v)MMN literature so far, it might be tenable that a threshold of deviance is involved in registering (v)MMN. While too small a magnitude of deviance might result in weakened vMMN, as seen in Shtyrov et al. (2013) and Experiment 2 of the current project, too large a degree of deviance might also lead to an absence of vMMN. In the current Spanish experiment, due to their high perceptual saliency, the symbols might overwhelm the early processing of the lexical stimuli in a non-attend condition. This is particularly the case where lexical stimuli serve as deviants and symbols as standards, since it has been shown previously that deviants play a more important role in the elicitation of lexical MMN (Shtyrov & Pulvermüller, 2002). With frequent presentations of the highly salient symbols (as standards), it might be difficult for the relatively “commonplace” lexical deviants to be processed.

The vMMN effect appeared only at late intervals after 370 ms. Interestingly, there were no differences between the three types of lexical stimuli. Again, the degree of saliency between symbols and the lexical stimuli might be responsible for this result. The perceptual difference was so large that the visual system might automatically categorise all the stimuli into two types: symbols and non-symbols. As no active processing of all perifoveal stimuli was encouraged in an attention-limited condition, there may have been no need for a fine-grained processing of the lexical stimuli into the three different sub-types, especially in an environment involving stimuli of high perceptual contrast. In agreement with this point, previous studies have also reported similar results. In a study to investigate task dependence on emotion word processing, Hinojosa, Méndez-Bértolo, and Pozo (2010) instructed participants to identify meaningful words among a string of nonsense symbols (Experiment 1) or pseudo-words (Experiment 2). Meaningful words included positive, negative and neutral words. In a rapid serial visual simulation (RSVP) paradigm, the non-recognisable symbols or pseudo-words were presented more frequently than the verbal stimuli, with a ratio of one word among four to seven symbols. Neither behavioural nor ERP differences were found among the different types of real words in the context of symbols, while clear differences were observed in the context of pseudo-words. The authors argued that the striking perceptual difference between real words and symbols may leave lexico-semantic processing of real words unnecessary for successful completion of the task. Similar findings were also reported in another study by the same research group (Hinojosa, Carretié, Valcárcel, Méndezbértolo, & Pozo, 2009). Further studies may explore the potential role of the deviance contrast in eliciting language-related vMMN.

4.6.4 Conclusion

The current experiment did not replicate the early vMMN effects in Experiment 1, although a similar experimental paradigm was adopted. This result, however, could possibly have been due to differences in saliency between the lexical stimuli and the radical-based symbols, which might also explain the late appearance of vMMN of similar size among the different lexical and word-like stimuli. To clarify this issue, further studies manipulating this factor are needed. Still a recent auditory MMN study (Shtyrov & Lenzen, 2017) on the early lexicality effect explored the difference between real and pseudo words separately in the sets of deviants and standards. This statistical method appeared to be sensitive for early differences between stimulus conditions. It may be an interesting option to test the current data in the future.

Chapter Five: General Discussion

This chapter is composed of four parts. Part 1 summarises the main findings from the six experiments. Part 2 gives a discussion of the results, which includes, first, the early time course, second, the automaticity of the lexico-semantic processing of Chinese single-character words; and third, the mechanisms of the language-related vMMN effect; Part 3 discusses the limitations of the current study and envisions directions for future research in this area. Part 4 concludes the thesis.

5.1 A summary of the main findings

Experiment 1 used well-matched Chinese single-character words and character-like stimuli presented in an identity oddball paradigm to explore whether the well-documented auditory MMN effects can be replicated in a visual modality. The presence of vMMN for real characters indicated that lexical information was processed early and automatically. In contrast, no sign of vMMN was found for pseudo-characters after 160 ms. In a control group of non-Chinese readers, no evidence of vMMN either in real or pseudo- characters was seen.

Experiment 2 explored how a reduced magnitude of deviance influenced vMMN elicitation, by directly comparing the physically similar real and pseudo-character in one oddball block. The results were very different from Experiment 1, in that no vMMN was elicited.

Experiment 3 investigated the effects of manipulating attention to lexical change. With direct attention to deviant stimuli, in an early time window, real characters yielded reduced vMMN, and pseudo-characters still did not show vMMN. In the later window after 300 ms, both real and pseudo- characters elicited vMMNs of similar amplitude. Taking these results together with those of Experiment 1, it seems that attention modulates vMMN in both early and late intervals.

Experiment 4 tested whether lexical frequency was processed early and automatically. It showed that only HF characters elicited early vMMN before 300 ms, and both HF and LF characters elicited vMMN at later windows after 300 ms.

Experiment 5 explored automatic semantic processing. Concrete words elicited enhanced vMMN relative to abstract words after 250 ms, although both of them elicited similar vMMN early around 200 ms.

Experiment 6 explored whether the language related vMMN effect might be replicated in Spanish, an alphabetic language. The results indicated real, pseudo- and non- words elicited vMMN only at a late interval after 300 ms and with no differences among the conditions.

5.2 Discussion of the main findings

In what follows the six experiments are examined together from the following aspects: early and automatic lexico-semantic processing and the mechanisms responsible for language-related vMMN.

5.2.1 *The early time course of lexical and semantic processing*

In Experiment 1, by comparing the difference ERPs for non-characters on the one hand and real plus pseudo- characters collapsed as structurally legal characters on the other, there was enhanced vMMN elicited by the "legal" characters at around 120-160 ms. Since all the legal characters share correctly positioned radicals, the enlarged negativity could suggest that the sublexical orthographic structure of Chinese single-character words is processed very rapidly. The cognitive system then appears to go on to discriminate real from pseudo- characters, as shown by a presence of vMMN effect for real characters and an absence of this effect for pseudo-characters. This lexical processing is evident during the interval of 160-200 ms. As an extension of this fast word form processing, in Experiment 4, lexical frequency information has also been found to be accessed within the first 200 ms. In addition, the differences between deviants and standards of different semantic categories are registered in ERPs and time-frequency representations before 300 ms in Experiment 5, signalling early processing at the semantic level. Taken together, the findings in these three experiments suggest that lexico-semantic analysis can occur within the first 300 ms after visuo-orthographic processing. These results fit well with what was found in the auditory MMN studies of lexical access (for a review, see e.g., Pulvermüller et al., 2009). It is noteworthy that due to the sequential unfolding nature of spoken words, previous auditory MMN studies normally time-lock ERPs to word recognition points rather than to word onsets in registering early linguistic effects. Therefore, the activation of word onsets may unavoidably influence the activation of critical recognition points, according to the Cohort model of speech processing (Marslen-Wilson, 1987; Shtyrov & MacGregor, 2016). The current study exclusively targets visual stimuli and calibrates the neurophysiological responses time-locked to the stimulus onsets, which cancel out the potential confound in the auditory field. Nevertheless, the current data agree well with those studies documenting early lexical and semantic access using other experimental designs such as classic LDT and semantic categorisation (Hauk et al., 2012; Hinojosa, Martín-Loeches, Munoz, Casado, & Pozo, 2004; Sereno & Rayner, 2003), thus providing strong evidence for early lexical and semantic processing.

Building from the first phase of processing, in the later windows after 300 ms, evidence of lexico-semantic processing has also been found in the rent experiments. In Experiment 1, while there is still no hint of vMMN in pseudo-characters, real character vMMN appears again in the interval of 330-370 ms. Similarly, in Experiment 4, HF characters also elicit vMMN in later windows. In Experiment 5, concrete characters start to elicit more negativity as well as larger theta power increase and PLF in the time-frequency domain than abstract ones after around 250 ms. These findings can be interpreted as reflecting secondary, in-depth lexical processing after the first stage processing. This pattern of results also largely overlaps with the findings in auditory MMN studies (Pulvermüller & Shtyrov, 2006), thus supporting modality-independent lexical and semantic processing in both early and late stages.

As stated in Chapter One, one of the challenging issues to be addressed in language science is how the different types of psycholinguistic information are processed in understanding an incoming word input. The above-mentioned findings of the similarly early timing of lexicality and semantics are in line with parallel processing models (Marslen-Wilson, 1975; Marslen-Wilson & Tyler, 1980; Posner & Pavese, 1998; Pulvermüller et al., 2009), which assume a roughly simultaneous access to various types of information at an early interval, followed by second-order reanalysis of these types of information. The current data thus do not seem to support serial (Fodor, 1983; Friederici, 2002; Friederici & Kotz, 2003) and cascaded models (Dell, 1986; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Garrod & Pickering, 2004; Hagoort, 2008). These two types of models similarly postulate a consecutive process starting from phonological and lexico-syntactic access, to lexical and semantic access and syntactic reanalysis. In particular, in these models, following the early effects of word category and syntax, word meaning is considered to be processed around 300-500 ms, as indexed by the N400 component, which is commonly elicited by a word's semantic incongruity with the preceding context (Kutas & Hillyard, 1980) as well as by other lexico-semantic factors, such as semantic concreteness and lexicality (Federmeier, Kutas, & Dickson, 2016; Holcomb et al., 1999; Holcomb & Neville, 1990; Pylkkänen & Marantz, 2003). Nevertheless, it should be pointed out that early parallel lexico-semantic processing as demonstrated in the current study is not necessarily in conflict with late N400-indexed lexical access. The two can be complementary in that complete linguistic processing may include both early lexico-semantic processing, as seen in the current study indicating first-order, automatic processing, and later, controlled and more fine-grained processing, as indexed by the N400 component.

To sum up, the current study is among the few investigations that have explored early language effects using a vMMN design. With its focus on the less-studied non-alphabetic Chinese, the study contributes novel evidence to current debates on language processing.

Before the ending of this section on the early time course of lexical and semantic processing, there is a need to discuss the latency variations found in the current experiments. In terms of the earliness of semantic change in Experiment 5 against the lexical change detection in Experiment 1 and previous vMMN studies (e.g., Shtyrov et al., 2013) and auditory MMN studies (Pulvermüller et al., 2007), the time range of lexical and semantic processing largely overlapped, albeit with a 20-50 ms variation. Considering differences in stimulus features such as word frequency and length, presentation time (100 ms in Shtyrov et al., 2013, 150 ms in the current experiment and 200 ms in Wang et al., 2013), distraction task difficulties (very demanding task in Shtyrov et al., 2013, and relatively easy task in Wang et al. 2013), such a variation of peak latency might not be surprising. To test directly the potential onset time difference for lexical and semantic processing, further studies with strict control of these above mentioned factors are needed. The research in this line is theoretically crucial in that it might shed further light on the cascaded vs. parallel processing debate.

5.2.2 The automaticity of lexical-semantic processing

In this thesis, the nature of lexical and semantic processing is explored by means of vMMN, as a neurophysiological indicator claimed to reflect automatic detection of changes (Stefanics, Kremláček, et al., 2014). When examining the issue of the automaticity of cognitive information processing in the visual mode, it is of course almost impossible to avoid engaging some degree of attention, particularly given the relative perceptive dominance of vision among other human senses. Nonetheless, it is still very important to carefully control attentional effects, in order to identify "genuine" vMMN effects (Stefanics, Kremláček, et al., 2014). In particular, the critical stimuli should be outside the attentional focus. Thus, in all the experiments of this study except Experiment 3, all the vMMN-eliciting stimuli were displayed in the periphery and the onset of these stimuli was independent from that of the attention-capturing distractors presented in the centre of the screen. A non-linguistic distraction task of continuously tracking the centrally-displayed fixation crosses was designed to minimise saccades to the perifoveal stimuli. (Note that a more closely control of attention can be achieved by combing an eye-tracker with EEG recording and should be encouraged in the future). Despite this stringent control of attention, the early vMMN effects were still reliably registered, reflecting responses to the manipulations of lexicality (Experiment 1), frequency (Experiment 4) and semantic concreteness (Experiment 5) in the linguistic stimuli, thus providing evidence that lexical and semantic processing are at least to some extent automatic. This pattern of results is consistent with a considerable number of previous studies investigating linguistic automaticity using different methods, such as Stroop tasks and variants of these (Glaser & Glaser, 1982; Stroop, 1935), although these studies typically present critical stimuli in the centre of visual focus area, which makes it hard not to attend to them on an otherwise blank screen (Czigler, 2007). The current data is also in agreement with those previous studies using masked priming paradigm (Dehaene, 2014) which have found evidence of lexical-semantic automaticity. In this a paradigm linguistic stimuli are made "invisible" using the masking technique but normally a language-related task, such as LDT, is implemented. Therefore, in comparison with these previous studies, the current investigation has implemented an improved design and thus provides strong evidence for lexico-semantic automaticity.

To further characterise the automatic nature of these processes, the current study has also been able to demonstrate how such linguistic automaticity may be modulated by attention and magnitude of deviance. Counter-intuitively, in Experiment 3, direct attention to the lexical deviants was found not to boost early detection of lexical changes, and instead resulted in an absence of pseudo-character vMMN and a reduced real-character vMMN in the early interval. In the auditory modality, however, with similarly directing of attention to deviants, the early MMN to pseudo-words was indeed found to increase, while the real word MMN remained unchanged (Shtyrov et al., 2010). While clarification of the inconsistent results demand more studies (especially those directly contrasting both auditory and visual lexical MMN effects), the divergent pattern of findings might be attributed to the different modalities of presentation. That is, the absence of early vMMN effects in the current study might be due to a possible inhibitory role of executive attention in the early visual target searching process. Indeed, a recent non-linguistic vMMN study (Kuldkepp et al., 2013) also reported a lack of vMMN in the early interval when attention was oriented to deviants. It should be noted, however, that previous vMMN studies with non-linguistic visual objects do find evidence for a facilitatory role of attentional resources in generating vMMN (Kimura & Takeda, 2013; Yucel, McCarthy, & Belger, 2007, but see, Kremláček et al., 2013) (A detailed description of the studies can be found in the discussion part of Experiment 3.). An important difference between these studies and the current experiment and Kuldkepp et al. (2013) is the way attentional resources are manipulated. These above-mentioned studies manipulated more attention to the critical stimuli by lowering the difficulty of centrally displayed distraction task. The logic here is based on the

Load theory (Lavie, 2005), which argues that the task-irrelevant distractors are perceived and processed when there are sufficient attentional resources. Therefore, the more difficult the primary task in the focus area, the less attentional resources are left for processing the stimulus information outside the attentional focus. These studies tend to suggest that increased attentional resources can enhance the amplitude of vMMN or even be a necessary condition in eliciting vMMN (Kimura et al., 2010b). To sum up, orienting attention to the perifoveal stimuli in the visual modality, which is different from the indirect way of reducing the difficulty of the central distraction task, seems to have a negative influence on the appearance of vMMN effects.

The other factor which has been found in the current study to influence automatic linguistic processing is the magnitude of deviance. Specifically, neither an excessively small magnitude of deviance (Experiment 2) nor an excessively large one (Experiment 6) appears to elicit vMMN. Too small a deviance may mean higher demands for the visual system to engage in in-depth processing to compare the standard and deviant stimuli, which is difficult to achieve in an attention-deprived condition. Thus the absence of lexical vMMN in Experiment 2. The lack of vMMN sensitivity to lexical status change in Shtyrov et al (2013) may speak in favour of this point. In this study, a comparatively delicate orthographic contrast (word-final consonant /K/ vs. /H/ in Russian) was shared among different lexical conditions. This small degree of deviance may not be salient enough to engage processing. On the other hand, in Experiment 6, with a large magnitude of deviance, the presentations of salient stimulus features (symbols) may overwhelm the perception of the non-salient features (letter strings, including real-/pseudo-/non- words), especially when symbols act as standards and letter strings as deviants in an oddball block. As a result, the alphabetic stimuli may be left without processing resources, leading to a lack of automatic lexical change detection and absence of vMMN. Therefore, a threshold-style of deviance might be a condition for automatic language-related change detection.

In sum, it has been found in the current study that the automaticity of lexical-semantic processing seems to be achieved only when the cognitive system is configured appropriately (Kiefer et al., 2012), especially with reference to the above-mentioned factors of attention and magnitude of deviance.

5.2.3 Language-related vMMN and categorisation

In a series of six experiments, the potential of the vMMN component to uncover the dynamics of linguistic processing, especially in early latencies has been demonstrated. The current vMMN investigations in the language area therefore represent a unique attempt to expand our knowledge of how words are fast and automatically processed in the brain. Written words and word-like stimuli such as those used in the current study can be regarded as a special type of visual objects, because they are a combination of "both a visual object and a linguistic entity" linked by orthography (Grainger, 2016). Therefore, both generic visual perception and linguistic processing are involved in the emergence of vMMN.

Underlying the language-related vMMNs may be a process of visual categorisation, which is automatic and obligatory in visual information processing (Greene & Li, 2014; Li et al., 2002). This categorisation process enables the memory system to go beyond simple visual features such as colour and line orientations and to represent complex visual information, including language (Czigler, 2013). From this perspective, the vMMNs to lexical legality and lexicality (Experiment 1), lexical frequency (Experiment 4) and semantic concreteness (Experiment 5) reported in the current study can be summarised as a result of category-based comparison between linguistic deviants and standards. Given that the linguistic stimuli have long-term memory representations in the human mind, such a comparison must take place between the two categories of memory representations accessed through the category members in an oddball block.

Recently, some MMN studies of visual or auditory sensory features (Grimm & Schröger, 2007; Kimura, Widmann, & Schröger, 2010a; Stefanics, Astikainen, et al., 2014) have suggested a predictive process in the deviance detection system (i.e., the prediction error account). According to this account, all the environmental regularities are held to be represented in the short term memory in a predicative manner, based on the frequent/repetitive presentation of standards. Presumably, this hypothesis may also explain the findings of the language-related studies which so far have indeed demonstrated vMMN effects in similar oddball paradigms (e.g., Wang, Wu, et al., 2013). However, due to the scarcity of this type of studies in the linguistic field and more importantly, the lack of vMMN studies directly comparing visual linguistic and non-linguistic features, it remains to be seen as to whether active prediction is involved in generating language-related vMMN effects.

5.3 Limitations and future directions

The current study is among the few attempts to explore early and automatic processing in the less-studied language of Chinese. Advancing from auditory MMN studies, the thesis has targeted MMN in the visual modality, an area still in its infancy, especially in the linguistic field. Therefore, inevitably, there are limitations to the work carried out, which are discussed below.

First, one unexpected result was that the Chinese lexical vMMN effect seen in Experiment 1 was not replicated in an alphabetic language (Spanish) in Experiment 6, thus possibly limiting the generalisation of these language related vMMN findings. Although the absence of vMMN could possibly be explained by design factors such as the large magnitude of stimulus change in this experiment, more studies with improved designs and in a variety of languages are needed in order to clarify the specific conditions under which language-related vMMN emerges.

Second, while the current study has demonstrated for the first time that vMMNs are sensitive to lexicality and semantic change, at least in Chinese single-character word recognition, it leaves one of the core features of language analysis, namely, syntax, unexplored. Investigating syntactic parsing in Chinese phrases/sentences can be challenging for a vMMN approach, which normally accommodates a single word once on screen, outside of the focus of attention. However, it is of theoretical significance for its relevance to language processing models as well as to the limitations of vMMN applicability in the language field. Thus, it is an important future direction for research.

Third, a direct comparison between linguistic and non-linguistic stimuli in terms of elicitation of vMMNs is necessary in order to identify and explore the characteristics that distinguish between these two qualitatively different types of visual stimuli. This line of research is important, as it has key relevance for different models of vMMN generation such as the prediction error account

(Stefanics, Astikainen, et al., 2014) and the categorisation account (Czigler, 2013) and therefore could contribute to understanding the underlying mechanism at play in early visual information processing.

Fourth, in this thesis, for consistency and comparison purposes, only the identity paradigm was adopted. Although this design has advantages in eliciting "genuine" vMMN through limiting N100/P100 confounding (Jacobsen & Schröger, 2003), at a pragmatic level, it is not time-efficient in registering vMMN, and a shorter experimental design would have benefits for participants. In addition, in the oddball paradigm, the unnaturally repetitive presentation of stimuli might also have a role in the earliness of the language effect. Thus, developing ecologically more valid protocols simulating normal reading with a variety of linguistic stimuli could be an important direction for future investigations. In contrast to elementary sensory auditory and visual features, linguistic stimuli are characterised by underlying long-term memory representations, such as syllabic and lexical information. This may imply that to establish a regular pattern using linguistic simulations in a sequence, it may not be necessary to have the massive repetition of a limited number of stimuli (e.g., Shtyrov & MacGregor, 2016).

5.4 Conclusions

In conclusion, this thesis has demonstrated through a series of six experiments that Chinese single-character words can be processed early and automatically. Even when the critical words are presented briefly and outside of the focus of attention, and when participants are instructed to do a non-linguistic distraction task, lexical and semantic vMMN effects can still be obtained within the first 250 ms. This result confirms and extends the findings in previous auditory MMN studies (Pulvermüller, et al., 2009) as well as those using classic paradigms such as LDT and masked priming (Dehaene, 2014). The similar early timing of vMMN responses to lexicality and semantics adds novel support for the parallel models in linguistic information processing. While lexical and semantic processing can occur out of attentional focus and under distraction conditions (i.e., automatically), this automaticity is found to be subject to configurations in the cognitive system, with attention and the magnitude of deviance as two important variables in particular. From the perspective of single word recognition, these findings contribute to scientific knowledge as to why normal reading can operate so fast and without apparent effort.

The current thesis work also points to the promise of vMMN designs in the empirical investigation of the high-order cognition of language, thus opening up new perspectives in language science endeavour. The linguistic vMMN effects in normal adults as seen in the current experiments may serve as a baseline for assessing the language ability development of children or second language learners. It may be possible to take advantage of this component to evaluate the linguistic processing capability of people with linguistic impairments, such as dyslexia.

Taken as a whole, although much remain to be addressed, this thesis work represents a first step forward in applying vMMN experimental designs to uncover the lexical and semantic processing dynamics of Chinese word recognition. It is hoped that the current study can inspire further research exploring language processing using vMMN as an index of earliness and automaticity.

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