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Comparing the Perceptual Abilities of Monolinguals, Bilinguals and Multilinguals: A Combined Behavioral and Event-Related Potential Experiment

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Comparing the Perceptual Abilities of Monolinguals, Bilinguals and Multilinguals:
A Combined Behavioural and Event-Related Potential Experiment

Ph.D. dissertation by Marie-Claude Tremblay
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Abstract

The aim of the experiment was to determine whether multilingualism contributes to the development of greater perceptual sensitivity to non-native speech contrasts. Combining an AX discrimination task and an Event-Related Potential experiment using an oddball paradigm, monolinguals, bilinguals and multilinguals were compared in their ability to discriminate a non-native contrast before and after receiving training as well as in their ability to transfer this training to a new but similar contrast. The experiment was based on a “pre-test – training – post-test” design, with 4 to 5 days between sessions. At the behavioural level, the effect of Group was significant only at Post-Test for the experimental contrast. Post-hoc analyses indicated that multilinguals were significantly more accurate than all of the other groups except for late bilinguals who were also more accurate than the control group which did not receive training. Moreover, multilinguals and late bilinguals were the only groups which improved significantly from Pre-Test to Post-Test. At the neurophysiological level, the effect of Group reached significance at Pre-Test for the experimental contrast and at Post-Test for both the experimental and transfer contrasts. At Pre-Test and Post-Test, monolinguals, late bilinguals and the control group exhibited a Mismatch Negativity (MMN) in the midline and the right side electrodes, while multilinguals and early bilinguals exhibited a bilateral MMN. The increase in MMN amplitude from Pre-Test to Post-Test was greater for multilinguals and both groups of bilinguals, compared to monolinguals and the control group. As for the Test of Transfer, monolinguals and the control group exhibited a right lateralised MMN, while multilinguals and both groups of bilinguals exhibited a bilateral MMN. The results of the behavioural and ERP experiments indicate that multilinguals and bilinguals have enhanced perceptual

sensitivity and a greater ability to learn a new contrast. Multilingualism seems to boost perceptual sensitivity and learning abilities. Moreover, the age at which a second language is learned may affect speech perception at both levels differently. Finally, since initial group differences were only found in the ERP data, the results indicate that differences at the neurophysiological level may transpire before or without any differences at the behavioural level.

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Chapter 1 – Introduction

Research has shown that linguistic experience shapes speech perception, causing it to shift from a language-general to a language-specific mode (Burns et al., 2007). The development of the first language (L1) phonological system during the first few years of life has the consequence of facilitating the perception of native contrasts while making contrasts that are not present in the linguistic environment harder and ultimately sometimes impossible to discriminate (Werker & Tees, 1984). This shift in perceptual sensitivity is, however, not permanent, as the ability to discriminate non-native contrasts can be recovered through training (Logan et al., 1991; Pruitt et al., 2006; Strange & Dittman, 1984; Tremblay et al., 1997; Tremblay et al., 1998; Winkler, Kujala et al., 1999; Zhang & Wang, 2007). At the neurophysiological level, learning to perceive a non-native contrast implies the development of new memory traces in the auditory cortex. Learning to perceive a new contrast therefore requires brain plasticity (Näätänen, 2001; Tremblay et al., 1997).

Thanks to their extensive language learning experience, multilinguals are often thought to have developed superior learning and processing skills (Nation & McLaughlin, 1986; Nayak et al., 1990; Thomas, 1988; 1992; Tremblay, under review). Is it also the case that individuals who have learned several languages have an enhanced perceptual sensitivity to new phonetic contrasts? Does having more experience learning languages contribute to the maintenance of a greater level of neurophysiological plasticity which in turn facilitates the learning of new phonetic contrasts? To date, the limited body of research, which comprises behavioural data only, is inconsistent, sometimes showing advantages for bilinguals and multilinguals over monolinguals (Enomoto, 1994), other times not (Devine et al., 1971;

Werker, 1986). Moreover, these studies only look at initial perceptual abilities, ignoring the potential impact of learning experience on learning rates (Werker, 1986).

The aim of the present study was to investigate the effect of language learning experience on speech perception. Combining behavioural (i.e. an AX discrimination task) and electrophysiological (i.e. an event-related potential (ERP) experiment using an oddball paradigm) methods, monolinguals, bilinguals and multilinguals were compared in their ability to discriminate a non-native contrast (voiceless aspirated dental/retroflex stop) before and after receiving training, as well as in their ability to transfer this training to a new but similar contrast (voiceless unaspirated dental/retroflex stop). The results of the behavioural experiment indicate that while performance on the discrimination task is similar regardless of language learning experience initially, it improves as a function of language learning experience after training. At the neurophysiological level, the results indicate that language learning experience affects both initial perceptual sensitivity and neurophysiological learning as a result of training. Moreover, the effect is also apparent at the level of transfer of learning. Overall, the results confirm that language learning experience boosts perceptual sensitivity and learning abilities. The results also indicate that differences at the neurophysiological level may transpire before or in the absence of differences at the behavioural level (K. L. Tremblay et al., 1998; present study).

1.1 Overview of the Chapters

First of all, a review of the literature is provided in Chapter 2. The review addresses issues such as behavioural and neurophysiological sound discrimination, levels of speech

processing, non-native contrast discrimination training, the effect of language learning experience on cognitive abilities, as well as some methodological issues as they pertain to testing speech perception. Chapter 3 provides the aim of the experiment as well as the specific research questions and hypotheses. This chapter also provides details regarding the methodology (i.e. participants, the stimuli, the methods and procedures). Chapters 4, 5 and 6 present the results for the training task, the behavioural discrimination experiment and the neurophysiological discrimination experiment respectively. Each of these chapters starts with the specific methods and procedures for the experiment, the statistical tests used to analyse the data as well as the results and a discussion of the results. Finally, Chapter 7 provides a general discussion of the results, making links between the behavioural and neurophysiological experiments. This chapter also presents conclusions regarding the effect of language learning experience (i.e. the number of languages learned and the age of second language acquisition) on speech perception. More specifically, claims are made concerning the effect of language learning background on perceptual sensitivity, learning abilities and brain plasticity.

Chapter 2 – Review of the Literature

2.1 Speech Perception

2.1.1 Behavioural Patterns of Speech Perception

2.1.1.1 Developmental Data: Monolingual Acquisition

Research has shown that speech perception is categorical. As Dehaene-Lambertz (1997) explains, “listeners are better able to discriminate equivalent acoustic differences when the difference signals a phonetic boundary than when it signals acoustic variants of the same phonetic category” (p. 919). For instance, given two pairs of sounds differing equally in voice-onset time (VOT), the pair that straddles the /ta/-/da/ categories is more easily discriminated than the pair for which both sounds are identified as being within the /ta/ category (Sharma & Dorman, 1999). While patterns of speech perception seem to be universal at birth (Werker & Lalonde, 1988), linguistic experience shapes speech perception such that, throughout the first years of life, the degree of sensitivity to certain acoustic details in speech sounds changes. Whereas sensitivity to acoustic differences that are not relevant for distinguishing meaning in the L1 is reduced (Burns et al., 2007; Kuhl et al., 2006; Werker & Tees, 1984; Werker & Lalonde, 1988), sensitivity to phonemic differences is maintained and sometimes enhanced (Polka et al., 2001; Sundara et al., 2006).

Among the most influential studies investigating the time course of the phonological development in young children is that of Werker, Tees and their colleagues (Werker et al., 1981; Werker & Tees, 1983; Werker & Tees, 1984). In their experiment comparing the ability of English-learning infants aged 6-8 months, 8-10 months and 10-12 months to discriminate two non-native contrasts (i.e. dental vs. retroflex stop found in Hindi and

glottalised velar vs. uvular stop found in Thompson¹), Werker & Tees (1984) demonstrate that, at 10-12 months, the infants' performance on the discrimination of both contrasts is significantly worse than that of their younger counterparts. In fact, the authors argue that the performance of these 10-12 month old infants is comparable to that of English-speaking 4 year olds and adults tested in previous work (Werker et al., 1981; Werker & Tees, 1983) who had lost the ability to discriminate these non-native contrasts.

It is now widely acknowledged, however, that not all native and non-native contrasts follow the same developmental pattern as the one attested by Werker & Tees (1984) (Best & McRoberts, 2003; Gervain & Werker, 2008; Polka et al., 2001; Sundara et al., 2006). For instance, Polka et al. (2001) and Sundara et al. (2006) found that exposure to the voiced dental stop vs. fricative (English) contrast leads to an increase in discrimination abilities for this contrast. The results of their experiment show that, up until 10-12 months of age, monolingual English and monolingual French infants do not differ significantly in terms of discrimination abilities for this contrast. By 4 years of age, however, monolingual English children discriminate /d/ vs. /ð/ more accurately than monolingual French children.

Moreover, the results show that whereas no effect of age is found for monolingual French infants and adults who were not exposed to the contrast, monolingual English adults performed significantly better than monolingual English infants and 4 year olds. It is also important to note that English 4 year olds performed significantly better than English 10-12 month old infants (Sundara et al., 2006). Based on these findings, it can be concluded that, in the case of the voiced (inter)dental fricative vs. stop contrast, lack of exposure does not

¹ A Salish language spoken in British Columbia, Canada, also called Nlaka'pamuctsin.

lead to a decline in perceptual abilities. Moreover, exposure has a facilitation effect that is noticeable at 4 years old and beyond (Polka et al., 2001; Sundara et al., 2006).

2.1.1.2 Developmental Data: Bilingual Acquisition

While studies on the developmental time course of speech perception have traditionally focused on monolingual contexts of language acquisition, a growing number of researchers have now turned to the investigation of speech perception development in bilingual contexts. Research on the perceptual abilities of children exposed to two languages from birth has yielded conflicting results. While some suggest that the process of tuning the perceptual system of two languages simultaneously may extend beyond the first year of life (Bosch & Sebastián-Gallés, 2003) and may not even be completed at 4 years of age (Sundara et al., 2006), others argue that the time course of the perceptual fine tuning is the same for monolinguals and bilinguals (Burns et al., 2007).

In an effort to learn more about how speech perception develops in a bilingual context of acquisition, Bosch & Sebastián-Gallés (2003) studied the discrimination of Catalan /e/ vs. /ɛ/ by monolingual infants exposed to Catalan or Spanish and by bilingual infants exposed to both Catalan and Spanish. The results of the experiment revealed that, at 4 months of age, all infants were able to discriminate the Catalan contrast irrespective of their linguistic environment. At 8 months of age, however, only the monolingual infants exposed to Catalan were able to discriminate the contrast. It is only at 12 months of age that bilingual infants regained the ability to discriminate the contrast like monolingual Catalan infants do at both 8 and 12 months old. Bosch & Sebastián-Gallés (2003) argue that the results

undermine the view that sustained exposure to specific contrasts suffices to maintain discrimination abilities. The process of perceptual reorganization from universal to language-specific seems to take place at a different pace depending on whether the child is exposed to one or two languages.

Sundara et al. (2006) also found evidence that the rate at which speech perception is modified by linguistic input might be slower in children exposed to two languages compared to those exposed to only one. The results of their experiment indicate that while four-year-old children exposed only to English are significantly better at discriminating the /d/ vs. /ð/ contrast than their four-year-old French speaking counterparts, bilingual children exposed to both English and French are not. Moreover, no significant difference is found between English monolingual adults and English-French bilingual adults. The results suggest that while perceptual facilitation for this contrast already manifests itself at 4 years old for children exposed to English only, it is not the case for children exposed to two languages. For bilingual children, facilitation seems to happen later than 4 years old (Sundara et al., 2006).

Burns et al. (2007), on the other hand, found no evidence of delays in the refinement of the representational system of bilinguals in relation to monolinguals. Their experiment investigated the time course of the shift in the perceptual boundary along the VOT continuum in monolingual English and bilingual English-French infants. The results showed that while both monolinguals and bilinguals were able to discriminate stops across the universal VOT boundary (i.e. 8 ms vs. 28 ms) at 6-8 months old, both groups were then

able to discriminate the typically English VOT boundary (i.e. 28 ms vs. 48 ms) at 8 to 10 months old. Furthermore, bilingual infants maintained the ability to discriminate the universal/French VOT boundary as well. Based on these results, the authors conclude that the development of perceptual categories in monolinguals and bilinguals follows the same path and time course.

2.1.1.3 Adult Data

Throughout the years, considerable research has been conducted on the discrimination of non-native speech contrasts by adults and several patterns have been identified. It has now been established, for instance, that, because these contrasts are not found in their phonological system, it is difficult for Japanese speakers to discriminate /r/ vs. /l/ (Callan et al., 2003; Golestani & Zatorre, 2004; Strange & Dittman, 1984; Zhang et al., 2005), for French speakers to discriminate /d/ vs. /ð/ (Sundara et al., 2006) and for Hungarian speakers to discriminate /e/ vs. /æ/ (Winkler, Kujala et al., 1999; Winkler, Lehtokoski et al., 1999).

It also interesting to point out that while it is difficult to perceive acoustic differences that do not signify a change in phonemic category in our native language, the ability to detect some non-phonemic acoustic differences is not completely lost. For instance, Best et al. (1988) found that American English 6-14 month old infants and adults alike are able to differentiate the voiceless unaspirated apical vs. lateral click contrast found in Zulu, with no exposure to the contrast. Furthermore, Zhang et al. (2005) investigated how language experience changes the perception of sounds by looking at the discrimination of /r/ vs. /l/

by American English and Japanese adults. As expected, the results showed that American English adults outperformed Japanese adults on an identification task and a discrimination task. It should be noted, however, that the Japanese participants, for whom the /r/ vs. /l/ contrast is not found in their native language, exhibited a greater sensitivity to within-category differences for the /l/ (Zhang et al., 2005). The authors interpreted these results as support for the view that linguistic experience shapes speech perception so as to direct the individual's attention to different acoustic details in the input. Unfortunately, this shift in attention is problematic for individuals learning the phonological system of a new language as it can make them focus on the wrong acoustic details.

It has also been suggested that being exposed to two phonetic categories that occur in allophonic variation in the first language does not suffice to maintain the ability to discriminate a contrast. Pruitt et al. (2006) addresses this issue by looking at the discrimination abilities of native speakers of Japanese and English on the Hindi dental and retroflex stops. Although dental and retroflex stops are both found in English, the distinction is not phonemic, but rather allophonic (i.e. allophones of the alveolar stop). Japanese /r/, which is a voiced flap/tap, is thought to be produced sometimes as an alveolar, sometimes as a retroflex. Since it contrasts with dental /d/ (and /t/), Japanese seems to have a contrast that is similar to the voiced unaspirated dental vs. retroflex contrast found in Hindi. The results showed that, on an identification task without any prior training, native speakers of Japanese did indeed outperform their English-speaking counterparts on this place of articulation contrast, not just in the voiced unaspirated context but on all voicing and aspiration contexts (i.e. voiced aspirated, voiced unaspirated, voiceless aspirated, voiceless unaspirated). The authors therefore conclude that phonemic experience is

required in order to maintain the ability to discriminate a contrast and that allophonic experience is not enough (Pruitt et al., 2006).

While developmental data suggest that speech perception develops similarly although possibly at different rates for individuals exposed to one or two languages from birth, these studies also show that, monolingual and bilingual adults alike are able to discriminate the speech contrasts in their respective language(s) (Sundara et al., 2006). Nevertheless, since little is known about the effect of bilingualism and the age of second language (L2) acquisition on speech perception in adulthood, it is important to take these factors into consideration when investigating perceptual abilities. Moreover, as will be discussed later on, the simple fact of having been exposed to more than one language may itself lead to differences in perceptual abilities.

While most speech perception studies have focused on the accuracy rates as a measure of discrimination abilities, a study by Shafer et al. (2004) indicates that it is also important to look at reaction times. In their study comparing the performance of native English and native Hindi speakers on a discrimination task that tested the dental vs. retroflex stop contrast, Shafer et al. (2004) found that while the two groups did not differ significantly with respect to their ability to discriminate the contrast, the reaction times of English speakers were significantly slower and more variable than those of Hindi speakers. The results suggest that reaction times may also reflect discrimination abilities.

2.1.1.4 Speech Processing Modes

The fine tuning of the perceptual phonetic system which starts in the course of the first year of life and which continues beyond school age (Best & McRoberts, 2003; Luksaneeyanawin et al., 1997, in Polka et al., 2001) is certainly advantageous for infants faced with the task of learning a language. Nevertheless, while infants benefit from the development of the sound system as it makes speech processing more efficient by enhancing perceptual sensitivity only to phonetic details that are relevant for the acquisition and processing of the L1, it also makes it increasingly difficult to acquire another language once the L1 phonological system has been established. It has been proposed that the difficulty adults have with perceiving certain phonetic differences could be related to the mode in which speech is processed by these individuals whose L1 phonological system is fully developed (Best et al., 1988; Flege, 1991). Flege (1991) suggests that a difference can be made between three levels of speech processing: auditory, phonetic and phonemic. At the auditory level, sounds are processed based on their acoustic properties without the interference of the L1 phonological filter. At the phonetic level, sounds are processed such that acoustic properties that are salient enough to potentially signal a phonemic contrast in some language are perceived (e.g., the difference between released and unreleased word-final stops in English, Flege, 1991, p. 407). At the phonemic level, sounds are processed at a more abstract level. In other words, sounds are perceived according to the abstract representations that constitute the phonological system. At this level, two sounds may be perceived as the same regardless of the acoustic differences between them.

The model proposed by Flege suggests that although a native and a non-native sound may be perceived as belonging to the same category at a phonemic and perhaps at a phonetic

level, there is a possibility that these two sounds will be perceived as distinct sounds at an auditory level, that is at a level at which acoustic details, even those that are not relevant in the L1 system, can be perceived. In a discussion on the effect of age on the acquisition of pronunciation, Flege (1987) proposes that what may differentiate younger language learners from older ones is the mode in which they process speech. On the one hand, because their L1 phonological system is still evolving, younger learners may be more inclined to process non-native speech sounds in an auditory mode, allowing them to attend to a greater range of acoustic characteristics present in non-native sounds. On the other hand, because their L1 system is fully developed, adult learners are more inclined to process speech in a phonetic mode (or even perhaps phonemic mode) and have more difficulty switching to an auditory mode of processing, thereby preventing them from assessing the acoustic characteristics of non-native sounds correctly (Flege, 1987).

While it is generally agreed that the difficulty with which adults discriminate certain non-native contrasts is related to the fact that they process speech through their L1 phonological filter, it is still not entirely clear why discrimination abilities differ from one non-native contrast to the next. On the one hand, it is a known fact that English speaking adults have difficulty differentiating a short lagged voiceless stop from a prevoiced one, even though both sounds are found in this language. On the other hand, English adults are able to perceive the difference between Zulu dental vs. lateral clicks, even though they have no exposure to these sounds (Best et al., 1988). Clearly, both developmental and adult data indicate that not all contrasts are equal and various accounts have been proposed to explain why some contrasts may be easier to discriminate than others (Best & McRoberts, 2003; Flege, 1991). While a detailed description of these models is beyond the scope of the

present discussion, it should be noted that the large body of research in the field of speech perception converge on the view that a combination of factors such as the structure of the phonological system of the L1 (Pruitt et al. 2006), exposure (Polka et al, 2001; Werker & Tees, 1984) and salience (Polka et al., 2001) greatly affect the extent to which a non-native contrast will be discriminated by an individual. It is therefore important to take these factors into account when designing or interpreting the results of perception experiments.

2.1.1.5 Speech Processing Modes and Behavioural Experiments

As mentioned in the previous section, several factors related to the individual's linguistic experience may have an effect on the perception of non-native speech sounds. It is important to draw attention to the fact that various experimental factors affect the way participants perform in speech perception studies as well. For instance, research has shown that the design of the discrimination task has a major impact on the level of processing and therefore on adults' ability to discriminate non-native contrasts (Werker & Logan, 1985).

In their study on the discrimination of a Hindi contrast by native speakers of English, Werker & Logan (1985) demonstrate that it is possible to manipulate the interstimulus interval (ISI) in order to probe the three different levels of speech processing introduced earlier: phonemic, phonetic and acoustic. On the one hand, a long ISI (1500 ms), because of its high memory requirements, is thought to tap into phonemic processing. An ISI of 1500 ms provides enough time for the auditory information of the stimulus to decay, forcing the individual to rely on the representations encoded in the phonological system to process the incoming stimulus. A short ISI (250 ms), on the other hand, has low memory demands and therefore allows for an acoustic mode of processing as the memory traces formed by the

stimulus are still accessible for comparison with the incoming stimulus. Processing speech at an acoustic level makes it possible for an individual to perceive changes in acoustic properties that occur in the stimuli even though these changes are not normally attended to when speech perception operates at the phonemic level. Werker & Logan (1985) believe that an intermediate level of processing, the phonetic level, also exists. At this level of processing, which is probed at an intermediate ISI (500 ms), individuals are sensitive to “non-native, phonetically relevant category boundaries” (Werker & Logan, 1985, p.43). Since the memory demands of the task determine the speech processing mode, the type of discrimination task is also likely to have an impact on performance. As a result, an ABX or AXB type of task, which requires the participant to compare sound X to two different sounds (A and B) in order to determine which sound is more similar to X, might yield different results than a less demanding task such as an AX task in which the participant is simply asked to determine whether the two sounds are the same or different (Werker, 1994; Werker & Logan, 1985).

2.1.2 The Neurophysiological Basis of Speech Sounds Discrimination

2.1.2.1 The Mismatch Negativity

Since speech perception is mediated by the encoding of the acoustic features of sounds in the auditory system (Kraus et al., 1995), it is also important to investigate sound discrimination at the neurophysiological level. ERP studies, for instance, have proven to be a valuable tool to investigate speech perception. The Mismatch Negativity (MMN) has been identified as a component that indicates the detection of a change in an ongoing sequence of similar auditory stimuli. The MMN is characterised by a negative deflection peaking between 100 and 250 ms following stimulus onset in the frontocentral electrodes

with a reverse polarity at the mastoids (Näätänen, 2001; Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993; Näätänen & Winkler, 1999; Tampas et al., 2005; Tiitinen et al., 1994). While the change in auditory stimulus need not be linguistically relevant to elicit an MMN (e.g. MMN elicited by frequency changes in tones: Cowen et al., 1993; Opitz et al., 1999; Näätänen, Schröger et al., 1993, Näätänen et al., 1994), this technique can be used to test the discrimination of phonemic contrasts by making the change one that crosses a phonological category boundary or not (Dehaene-Lambertz, 1997; Näätänen et al., 1997; Sharma & Dorman, 1999; Tremblay et al., 1997; Winkler, Kujala et al., 1999).

Before going further into the review of the main findings of ERP experiments as they pertain to the perception of speech sounds, it is necessary to review the basic neurological mechanisms responsible for the MMN in order to fully understand how the resulting ERP component can be interpreted in terms of speech sound discrimination. First of all, when a sound is heard, a temporary sensory trace is created based on how the sound is perceived (Näätänen, 2001; Näätänen & Winkler, 1999). After several seconds, if the representation of the sound is not reinforced by repetitive stimulation, the trace will decay (Cowen et al., 1993; Näätänen, 2001). However, if the representation is strengthened by repetitive stimulation (as in the case of the “standard” in an oddball paradigm), the trace becomes stronger and less susceptible to decay. Note that repetitive stimulation does not necessarily imply the repetition of an identical sound. The central auditory system is able to extract the regularities found in a sequence of similar sounds in order to develop the sensory memory traces such that some variation is possible (Näätänen, 2001; Näätänen & Winkler, 1999). For instance, the sequence of standard sounds can consist of different recordings of the same syllable or phonetic category or of tone pairs of different frequencies that show the

same pattern (e.g. all standards are ascending tone pairs and the deviant are descending tone pairs; Saarinen et al., 1992). The acoustic analysis system uses this sensory trace as a comparison for incoming stimulation. When an incoming sound does not match the sensory memory trace, an MMN is elicited (Cowen et al., 1993; Näätänen, 2001).

Some have proposed that at least two different mechanisms are responsible for sound analysis: acoustic and speech sound analysis mechanisms (Näätänen, 2001). In terms of levels of speech processing, these two types of mechanisms refer to the auditory and phonetic/phonemic² levels described earlier. In addition to being analysed acoustically in the way just described, speech sounds are thought to be analysed by a system of permanent memory traces as well. These memory traces, which encode the phonemes that constitute the phonological system of the L1, are used to categorise incoming speech sounds (Näätänen et al., 1997; Näätänen, 2001).

Functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG) experiments suggest that phonetic memory traces are found in the area of the left auditory cortex (Golestani & Zatorre, 2004; Näätänen et al., 1997) possibly in the posterior part, near or in Wernicke's area (Näätänen, 2001). When the trace encoding the representation of a phonetic category is repeatedly activated (again as in the case of the standard in an oddball paradigm) and then a sound not matching this representation is suddenly heard, an MMN is elicited (Näätänen, 2001). It is important to mention that not all phonemically

² In the ERP literature, speech processing is only discussed in terms of two levels of processing (i.e. acoustic/auditory and phonetic). Therefore, the phonemic and phonetic levels will not be differentiated in the discussion of sound processing at the neurophysiological level and the term phonetic will be used to refer to both.

contrastive pairs of sounds that elicit an MMN have the same generators. Support for this claim comes from various types of data such as research findings on aphasia and other language or auditory system impairments that indicate that the MMN effects elicited by different types of acoustic changes are not all equally affected. For instance, in the case of individuals suffering from aphasia who had lesions in the posterior temporal lobe, a change in pure tone elicited an MMN while a phonetic vowel change did not (Aaltonen et al., 1993). Relying on MMN recordings from subdivisions of auditory thalamus and epidural surface in guinea pigs, Kraus et al. (1994) were able to demonstrate that an MMN that is elicited by a change in temporal cues is generated in different areas of the brain compared to an MMN that is elicited by a change in spectral cues³. On one hand, an MMN that is elicited by a change in temporal cues, such as the formant transition duration difference between /ba/ and /wa/, may involve the non-primary auditory thalamus. On the other hand, an MMN that is generated by a change in spectral cues, such as the difference in formant transition frequency between /ga/ and /da/, does not involve any substantial increase in activity in that region (Kraus et al., 1994). The authors propose that spectral changes could be processed more cortically. It is interesting to note that, regardless of the differences in the responses recorded by the intracranial electrodes, Kraus et al. (1994) report a similar MMN in the surface midline electrodes for both types of contrast. Although it is not clear how differences at the level of the generators translate in differences in MMN recordings at the surface level, it is important to take into consideration both the phonological status and the nature of the change when interpreting and comparing the results of the numerous

³ Kraus et al. (1995) make a distinction between the encoding of stimulus and the encoding of stimulus change. The authors argue that whereas the features of non-changing stimuli are represented in the “domain of the primary system” (p.25), the changes in acoustic features are encoded elsewhere and involve “major contributions from the nonprimary auditory thalamocortical pathway as well as input from primary and association auditory cortex” (p.25).

studies which have relied on the MMN in order to investigate the discrimination of native and non-native contrasts.

2.1.2.2 Discrimination of Native and Non-Native Contrasts: Developmental Data

Developmental studies of speech perception that investigated whether the changes in behavioural patterns of sound discrimination observed in infants are a reflection of changes at the neurophysiological level suggest that language-specific memory traces are already developing by the time infants celebrate their first birthday. This is attested by the fact that, by the end of the first year of life, the MMN response to non-native contrasts is decreased for both vowels (Cheour et al., 1998) and consonants (Rivera-Gaxiola et al., 2005).

Conversely, during the same period of time, the MMN elicited by a native contrasts seem to increase (Cheour et al., 1998; Rivera-Gaxiola et al., 2005). Electrophysiological patterns of discrimination therefore seem to echo the behavioural patterns of decrease of sensitivity to non-native contrasts and of facilitation effects for native contrasts (Polka et al., 2001; Sundara et al., 2006).

2.1.2.3 Discrimination of Native and Non-Native Contrasts: Adult Data

Considerable research has been conducted in an attempt to determine whether, despite the fact that non-native contrasts are difficult to discriminate behaviourally, they can be discriminated pre-attentively, at the neurophysiological level. For instance, Rivera-Gaxiola et al. (2000) conducted an experiment that investigated the electrophysiological responses to a native and non-native contrast. Their study, which looked at the discrimination of /da/ vs. /ba/ (native contrast) and the /da/ vs. /ɖa/ (non-native: dental vs. retroflex) by native

speakers of English indicated that an MMN was generated by both types of contrasts, despite the fact that only the native contrast was discriminated behaviourally.

Relying on the assumption that native and non-native contrasts are processed at the phonetic and acoustic level respectively, a number of experiments have employed these two types of contrasts in order to investigate the different modes of speech processing.

Numerous studies have been conducted to figure out how acoustic and phonetic speech processing operates. Evidence for differences between auditory and phonetic processing in terms of amplitude, location, and timing has surfaced. Sharma & Dorman (1999), for instance, demonstrated that while both a within and an across category sound change can generate an MMN, the phonetic status of the sound change affects the neurophysiological response. Their experiment showed that English speakers were able to discriminate both a change in VOT from 30ms to 50ms (from /t/ to /d/) and from 60ms to 80ms (within the /t/ category) as evidenced by an MMN for both conditions. Nevertheless, the amplitude of the MMN elicited by the across category sound change was significantly larger than that of the MMN elicited by the within category change.

Dehaene-Lambertz (1997) also found evidence for differences between within and across category discrimination. In this experiment, native speakers of French were tested on their sensitivity to changes of equal acoustic difference within and across a phonemic boundary for both a native and a non-native contrast. The results showed that, for the native contrasts, although an MMN was elicited by both the within and across category change (/ba/ to another /ba/ and /ba/ to /da/ respectively), the amplitude was significantly greater for the latter. Moreover, the sound change that crossed the phonetic boundary (i.e. /ba/ to /da/) also

showed an asymmetric pattern of activation while the purely acoustic change (i.e. /ba/ to another /ba/) did not. The results also revealed that no such difference was found between the within and across category boundary for both non-native contrasts (/da/ to another /da/ and /da/ to /qa/ respectively). In fact, the results showed that no negative deflection was observed in the MMN window for either type of change suggesting neither of the differences were detected. Dehaene-Lambertz (1997) concludes that the results demonstrate that the MMN is not simply an index of acoustic discrimination but rather that it is also modulated by phonemic differences.

More recently, Dehaene-Lambertz et al. (2005) also carried out an experiment aimed at investigating acoustic and phonetic speech processing. In order to do so, a set of stimuli was created that consisted of sinusoidal waves mimicking CV syllables. The sine waves differed in frequency in a way that replicated the F2 and F3 transitions continuum from /ba/ to /da/. The non-speech stimuli were presented in 2 different conditions, first in a non-speech condition and then in a speech condition for which participants were trained to perceive the sinusoidal waves as syllables (i.e. /ba/ and /da/). In both conditions, participants were tested on their ability to discriminate a within-category change (i.e. different token of /ba/ or /da/ judged as being within the same category boundary) and an across category change (i.e. from /ba/ to /da/ and vice versa). The results of the ERP experiment revealed a significant MMN for both the speech and non-speech condition suggesting that the changes were detected by participants. The analysis also revealed that, in the speech condition, the MMN evoked by the across category change had a shorter latency and longer duration compared to the within category change. Moreover, whereas

both the speech and non-speech modes exhibited a left hemisphere dominant activation, the asymmetry was more prominent for the speech mode. The authors also note that the decrease in latency and increase in duration of the MMN were correlated with increased behavioural discrimination abilities. The results of this experiment support the claim that acoustic differences are processed in a different manner depending on whether they are perceived in a linguistically relevant way or not. Furthermore, as the authors point out, the fact that these differences were only observed in the speech condition regardless of the fact that the exact same stimuli were presented in the two conditions, suggests that the categorical effect observed for speech stimuli is specific to the processing of linguistically relevant stimuli (Dehaene-Lambertz et al., 2005).

In an attempt to explain the differences in MMN effects between the processing of acoustic and phonetic sound differences, Näätänen (2001) suggests that “both speech and complex non-speech sounds activate acoustic sound-analysis mechanisms, but only speech sounds activate the speech-sound traces or recognition models” (p.8). In other words, there could be two types of sound-analysis systems, one that analyses all sounds acoustically and one that analyses sounds linguistically if they are recognised as speech sounds. This claim is supported by MMN experiments that have shown that the increase in negativity is measured at different electrodes sites depending on whether the change is perceived as an acoustic or a phonetic change. On the one hand, the acoustic MMN, which can be elicited by a change in both non-speech sounds (e.g. tone frequency) or speech sounds that are not perceived phonetically (as in the case of a within phonemic category changes), is characterised by an increased negativity that is bilateral (Näätänen, 2001; Sharma & Kraus, 1995, in Näätänen, 2001). On the other hand, the phonetic MMN is larger in amplitude and

left-lateralised (Näätänen et al., 1994; Näätänen, 2001). Näätänen (2001) attributes this left lateralisation of the phonetic MMN to the double activation in the left auditory cortex (for acoustic and speech sound analysis).

It is important to note that not all ERP studies comparing within and across category discrimination support this view. Several studies have reported a comparable MMN amplitude for contrasts differing in phonetic status (Maiste et al., 1995; Sharma et al., 1993, in Sharma & Dorman, 1999). In their experiment investigating the timing of acoustic and phonetic speech processing, Winkler, Kujala et al. (1999) demonstrated that pre-attentive discrimination of stimuli changes, as evidenced by the MMN, relies on a simultaneous rather than sequential processing of auditory and phonetic information. The authors studied processing differences between sound changes based on whether they represent a change within the same phonemic category (non-native contrast) or across a phonemic category boundary (native contrast). In order to do so, the authors looked at the electrophysiological responses of Hungarian and Finnish speakers to two vowel contrasts, one that is contrastive for the Hungarians but not for the Finnish participants (i.e. /ɛ/ vs. /é/⁴) and the other that is contrastive for the Finnish but not for the Hungarians participants (i.e. /e/ vs. /æ/). The results of their experiment show that not only did both contrasts evoke an MMN in both groups of participants but also no evidence of earlier or later processing of auditory (sensory) versus categorical (phonetic) discrimination was found (Winkler, Kujala et al., 1999).

⁴ Hungarian /é/ appears to have a slightly lower F1 frequency and higher F2 frequency compared to Finnish /e/. See Winkler, Lehtokoski et al. (1999) for more details.

Some of the discrepancies in the results regarding acoustic and phonetic processing could be explained by the fact that a wide variety of stimuli was used in MMN experiments (Rivera-Gaxiola et al., 2000; Sharma & Dorman, 1999). Whereas the contrasts tested in Sharma & Dorman's (1999) experiment involved a change along the VOT continuum, other experiments have tested contrasts that involve a change in place of articulation (i.e. differences between formant transition for F2 and F3). Moreover, while some have tested consonant contrasts, others have tested vowel contrasts (Winkler, Kujala et al., 1999). As discussed earlier, the type of acoustic change can have an impact on the MMN (Kraus et al., 1994). Moreover, Dehaene-Lambertz (1997) points out that some ERP experiments may have failed to find differences between the acoustic and phonetic processing of sound changes because an insufficient number of electrodes were used for data collection. Dehaene-Lambertz (1997) makes the observation that no difference in MMN would have been observed if, as is done in other experiments, Fz (a frontal electrode along the midline) was the only electrode considered.

2.1.2.4 Methodological Considerations for the Mismatch Negativity

Various factors may have an effect on the nature of the neurological response triggered by sound discrimination. As mentioned earlier, the choice of stimuli (i.e. native vs. non-native contrast; change in temporal vs. spectral cues) may influence the MMN. Studies have also shown that increasing the acoustic difference between the standard and the deviant affects the MMN (Näätänen et al., 1994; Lang et al., 1990). Tiitinen et al. (1994) found that, as the difference in frequency (Hz) between the standard and the deviant increases, the amplitude and duration increased and latency decreased. When it comes to speech sounds, however, Näätänen et al.'s (1997) ERP experiment suggests that phonemic status and degree of

acoustic difference influence the MMN in different ways. On the one hand, a MMN of greater amplitude was recorded when the change in stimulation crossed a phonemic boundary than when it did not, regardless of the fact that the acoustic difference was greater for the latter. On the other hand, latency was shorter for the acoustically more distinct contrast than the less acoustically distinct contrast, regardless of whether it crossed a phonemic boundary or not (Näätänen et al., 1997).

Not only can the choice of contrast affect the amplitude of the MMN, but the order of presentation as well. Shafer et al. (2004) found that the MMN elicited by the contrast /ba/ vs. /da/ in English and Hindi speakers had an earlier latency when /ba/ was used as the standard than when /da/ served as the standard. The authors interpret these results as an indication that the two consonants are represented differently neurophysiologically. The memory traces for the two consonants might differ based on their different phonetic status, the retroflex being more marked than the bilabial.

It has been suggested that the nature of the stimuli could also have an effect on the MMN (Pettigrew et al., 2004; Tampas et al., 2005). Since the MMN can also indicate the detection of acoustic changes in the stimuli, some have privileged the use of synthetic stimuli over the use of natural speech stimuli (Dehaene-Lambertz, 1997; Sharma & Dorman, 1999; Tremblay et al., 1997; Winkler, Lehtokoski et al, 1999). Doing so insures that the increase in negativity elicited by the change from the standard to the deviant is not affected by an increase in negativity caused by other acoustic differences that are not relevant to the contrast being tested. In their study comparing speech (CV syllables) and

non-speech (simple tones) stimuli, Pettigrew et al. (2004) found that only the non-speech stimuli elicited a robust MMN. The results of their study also indicate that a difference in intensity (75 vs. 60 dB HL) and duration (50 vs. 20ms) between the standard and the deviant evoke an MMN of greater amplitude than a change in frequency (600 vs. 650 Hz) (Pettigrew et al., 2004). The authors conclude that this may explain why it is more difficult to observe an MMN using stimuli for which the difference between the standard and the deviant is a change in frequency that is embedded in complex speech sounds (Pettigrew et al., 2004).

Research indicates that increased attention to the stimuli may increase the amplitude of the MMN. For instance, Näätänen and his colleagues (Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993) observed that a MMN of larger amplitude was elicited in participants asked to actively discriminate the deviant sound in an oddball paradigm than in participants asked to ignore the stimuli and read a book. Moreover, various studies have found that a P300 may be elicited when participants are consciously discriminating the sound change (see Section 2.1.2.6 for more details on the P300). For this reason, most studies use a distractor task while the stimuli are playing in order to keep participants' attention away from the auditory stimulation and therefore ensure that the level of attention to the stimuli is similar for all participants. A distractor task may consist of reading a book (Saarinen et al, 1992; Tiitinen et al, 1994; Winkler, Lehtokoski et al., 1999) or watching a video either with subtitles (Dalebout & Stack, 1999; Pettigrew et al., 2004; Tampas et al., 2005), the soundtrack played at a volume lower than the stimuli (Sharma & Dorman, 1999) or without subtitles and sound (Rivera-Gaxiola et al., 2005). Some have argued that videos are preferable since it is easier to watch a video for an extended period of time than to read

(Kraus et al., 1995). Tampas et al. (2005) point out that the presence or absence of subtitles does not affect the MMN. While attention can modulate the MMN, it is important to note that this ERP component can be observed whether the individual pays attention to the stimuli or not (Näätänen, 2001; Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993).

Since the sensory memory traces established by the standard in an oddball paradigm decay over time (Cowen et al., 1993; Mäntysalo & Näätänen, 1987; Böttcher-Gandor & Ullsperger, 1992), it is reasonable to question whether the length of the ISI has an impact on the MMN. Mäntysalo & Näätänen (1987) set out to investigate whether an MMN could be elicited even with a longer ISI. The results show that while an ISI of 1 second and of 2 seconds did generate an MMN, a longer ISI such as 4 and 8 seconds did not. Böttcher-Gandor & Ullsperger (1992) also investigated this question by randomly varying the ISI between 1, 6 and 10 seconds within the same experimental block. The results showed that neither amplitude nor latency was modulated by the difference in ISI. Pettigrew et al. (2004) also found that a difference in stimulus onset asynchrony (SOA) between 610 ms and 900 ms did not affect the MMN when speech stimuli were used (CV syllables). These results suggest that, while an MMN might not always be elicited by a long ISI (i.e. of over 4 seconds), a shorter ISI does and variation within a certain range does not appear to affect the amplitude or latency of the MMN. Unlike for behavioural studies, the ISI used in the oddball paradigm of an electrophysiological discrimination experiment does not seem to affect the mode of speech processing.

Another important methodological issue is one that pertains to the relationship between habituation effects and signal-to-noise ratio (SNR). Because of the nature of ERP data, the SNR is often so low that it is difficult to infer anything from individual averages or even from small group averages. In order to obtain a higher SNR, it is therefore necessary to maximise both sample size and testing time. On the one hand, anyone who has ever dealt with human subjects is aware of the fact that finding participants who correspond exactly to a set of predetermined criteria is not always a simple task. On the other hand, extending the testing time is not ideal either for a couple of reasons. First of all, participants get bored and tired as a result of lengthy periods of data collection. Second of all, research indicates that the MMN is subject to habituation effects such that, after 10-15 minutes, the strength of the MMN, for both easy and hard to discriminate contrasts, is thought to be significantly attenuated (McGee et al., 2001). As a result, extending the data collection time beyond 10-15 minutes, without rest periods (which have shown to lead to recovery in MMN responses), would have an adverse effect on the SNR rather than improve it (McGee et al., 2001). It is therefore crucial, when designing the experiment, to strike a realistic balance between sample size and testing time in order to maximise to the extent possible the SNR.

Deviant probability is another factor to consider when designing an MMN experiment. The frequency with which the deviant sound is introduced among the sequence of standard sounds seems to have an impact on the MMN. A study by Näätänen and his colleagues indicates that a difference in the deviant probability of 2% and 10% has an effect on the MMN such that the amplitude of the electrophysiological response to the sound change is larger when the deviant probability is smaller (Näätänen et al., 1983, in Mantysalo & Näätänen, 1987). Sato et al. (2000) also investigated the effect of deviant probability on the

MMN. They compared the MMN recorded in Fz and T4 and T6 when the deviant probability was 5%, 10%, 20% and 30%. The results of this experiment show that deviant probability affects the MMN differently in different electrode sites. Whereas, a MMN started to be recorded in Fz only as the deviant probability was smaller, an MMN was recorded in the temporal electrodes (T4 and T6) even at the greater deviant probability. The authors suggest that this difference could stem from difference at the level of the MMN generators. The frontal MMN generators (recorded in Fz) may need a stronger memory trace (which is reinforced by a smaller deviant probability) for an MMN to be generated.

2.1.2.5 Other Neurophysiological Methods

It should be noted that the evidence for the processing differences between native and non-native contrasts, or, put differently, between acoustic and phonetic discrimination, that has transpired from electrophysiological experiments is supported by MEG and fMRI data (Zhang et al., 2005; Golestani & Zatorre, 2004). In the same study mentioned earlier on the discrimination of /r/ and /l/, Zhang et al. (2005) also collected MEG data in order to investigate the magnetic equivalent of the MMN, the Mismatch Field (MMF) evoked by the /r/ vs. /l/ contrast in Japanese and American English speakers. The results indicated that the MMF observed for the two groups of participants differed not only in terms of amplitude (i.e. MMF of significantly greater amplitude for American English than Japanese speakers), but it also differed in terms of where the peak amplitudes were recorded. Whereas a significantly greater amplitude was recorded in both hemispheres in both groups of participants, greater peak amplitudes were observed in the left hemisphere than in the right for the English speakers such that the difference between the left and the right was nearly statistically significant (Zhang et al., 2005). It should be noted that Zhang et al.

(2005) also found that the MMF observed for the Japanese speakers was significantly earlier than for the American English speakers. The authors point out that this result is surprising given that earlier latencies are usually correlated with a greater amplitude. Zhang et al. (2005) propose that this could be due to the fact that, as opposed to English speakers who discriminate /r/ and /l/ by integrating the difference in the steady portion of F3 (early) as well as in its transition (late), Japanese speakers process these two differences sequentially. While Japanese speakers may show an earlier MMF caused by the difference in the steady portion of F3, English speakers do not. The results of this experiment clearly reflect the differences between native and non-native speech processing that emerged from ERP experiments.

Results of experiments based on fMRI technology also suggest that native and non-native contrasts are processed in a different manner. For their part, Golestani & Zatorre (2004) conducted an fMRI experiment that investigated the discrimination of a native contrast (/da/ vs. /ta/) and a non-native contrast (/da/ vs. /qa/) by native speakers of English. The results show that, upon first exposure, the non-native contrast activated only left insula – frontal operculum whereas the native contrast elicited a more bilateral activation in various areas (i.e. left insula – frontal operculum, left inferior frontal gyrus and the left and right superior temporal gyri). The different patterns of activation observed for the native and non-native contrast suggest that acoustic differences are processed differently depending on their phonological status in the individual's first language. The results are in agreement with those of Callan et al.'s (2003) fMRI experiment which also found different patterns of brain activation for these two types of contrasts.

2.1.2.6 The P300

Another ERP component that can be interpreted as a measure of sound discrimination is the P300 (Dalebout & Stack, 1999; Tampas et al., 2005). The P300 is a positive deflection peaking at around 300 ms after stimulus onset with maximum amplitude at the midline, more specifically at the centro-parietal electrodes (Tampas et al., 2005). As opposed to the MMN, which is a pre-attentive component, the P300 “requires attention to, and conscious discrimination of, stimulus differences” (Dalebout & Stack, 1999, p. 388). It has been proposed that the MMN and the P300 could reflect different levels of speech processing (Dalebout & Stack, 1999).

In their experiment, Dalebout & Stack (1999) compared pairs of stimuli along the /ba/-/ga/ continuum that differ with respect to how easily they could be discriminated behaviourally. The results of the analysis revealed that while a P300 was systematically recorded for the easily discriminated stimulus pair, no P300 was recorded for the pair of stimuli that participants had difficulty discriminating behaviourally. The results therefore suggest that the P300 may signal sound discrimination abilities. It is also interesting to note that the authors found no clear correlation between behavioural discrimination and the presence or absence of the MMN.

Tampas et al. (2005) compared the electrophysiological and behavioural responses to a speech (within category CV) and non-speech (frequency glide mimicking the CV speech stimuli) contrast of equal acoustic distance. The results showed that the non-speech contrast but not the speech contrast elicited an MMN. It is important to note however, that the results are only reported with respect to Cz (a central electrode in the midline) and that a

greater number of channels may have revealed that an MMN of smaller amplitude was also found for the speech contrast, possibly at different electrode sites (Dehaene-Lambertz, 1997; Näätänen, 2001; Sharma & Kraus, 1995). With respect to the P300, this component was elicited by both contrasts. Nevertheless, the P300 observed for the non-speech stimuli was of greater amplitude and shorter latency than the one observed for the speech stimuli. The authors interpret the results as indicating that speech and non-speech sounds are processed differently very early on. In other words, as early as during the MMN window, speech sounds are processed categorically (Tampas et al., 2005).

2.1.3 Training and Learning Effects: Behavioural and Neurophysiological Evidence

2.1.3.1 Training

Fortunately, the shift in perceptual sensitivity which takes place in the first years of life and which makes it difficult for adults to discriminate certain contrasts does not seem to be permanent. A remarkable characteristic of the brain is that it is very adaptive. It is thanks to brain plasticity that the ability to discriminate non-native contrasts can be recovered through training (Golestani & Zatorre, 2004; Kraus et al., 1995; Näätänen, 2001; Tremblay et al., 1997; Tremblay et al., 1998; Winkler, Kujala et al., 1999; Zhang & Wang, 2007).

Over the years, valuable information has emerged from training studies which has led to the development of increasingly efficient and elaborate training techniques. In their study, Pruitt et al. (2006) compared the discrimination abilities of English and Japanese speakers on the dental vs. retroflex place of articulation contrast. As mentioned earlier, while these sounds are not phonemically contrastive in English, they are, to some extent, in Japanese. Pruitt et al. (2006) relied on an extensive training procedure which allowed them to assess

discrimination abilities before and after training. Participants took part in 12 training sessions throughout which the training stimuli were becoming increasingly difficult. The level of difficulty was increased in two ways: by gradually lengthening the vowel in the CV syllables and by increasing the number of speakers from one to six. The purpose of including several speakers in the training stimuli is to expose participants to some variability which in turn favours the abstraction of the general features of each category while ignoring acoustic idiosyncrasies. The results of the analysis revealed that, when tested on the same materials they were trained on, both English and Japanese speakers improved significantly from pre-test to post-test. Pruitt et al. (2006) were also interested in determining to what extent participants were able to generalise what they had learned based on a limited set of training materials to a more exhaustive set of stimuli. While participants were trained on the voiced aspirated dental vs. retroflex place of articulation in an /a/ and /o/ vowel context, the pre-test and post-test included an extra vowel context (i.e. /e/) and three additional voicing/aspiration conditions (i.e. voiced unaspirated, voiceless aspirated and voiceless unaspirated). Tokens produced by a speaker who did not appear during training were also part of the pre-test and post-test materials. The results of the analysis showed that improvement from pre-test to post-test was comparable for all vowel contexts and participants improved on both the trained-on and untrained-on speaker. Furthermore, while participants improved most on the voiced aspirated condition, there was evidence of significant improvement on the other voicing/aspiration conditions as well. The authors therefore interpret the results as evidence of transfer of training.

Tremblay et al. (1997) also studied the effect of training on discrimination abilities and transfer of learning. Furthermore, they were interested in finding out whether the changes

observed at the behavioural level were also reflected at the neurophysiological level. In order to do so they tested monolingual English speakers on their ability to discriminate a non-native 10 ms VOT contrast (-10 ms vs. -20 ms) along the labial and the alveolar place of articulation continuum. While participants were tested before and after five training sessions (on five different days) on both contrasts, they only received training on the labial one. The results of the behavioural discrimination and identification tests corroborate those of Pruitt et al. (2006) as participants not only performed significantly better at post-test on the labial contrast, but they were also able to transfer the training to another similar non-native contrast. Research therefore suggests that transfer of learning is possible whether transfer is from one voicing/aspiration condition to another (keeping the place of articulation constant) or from one place of articulation to another (keeping VOT constant).

Tremblay et al. (1997) were also able to demonstrate that training translates into changes at the neurophysiological level as well. This is supported by the fact that a shorter onset latency, longer duration and larger area were measured for the MMN at post-test versus at pre-test for the training contrast. Moreover, a longer duration and an increased area were also recorded for the MMN for the transfer contrast at post-test. The results indicate that, similarly to what was observed at the behavioural level, changes in discrimination abilities at the physiological level due to training are also generalizable to similar but different stimuli for which no training is received. It is also important to point out that the changes in electrophysiological response to the change in the labial contrast at post-test were greater over the left hemisphere such that onset latency decrease and the duration increase were more significant in the left electrode sites than in the right ones. Tremblay et al. (1997) propose that this could be due to the fact that, as a result of training, participants went from

processing the non-native VOT contrast as an acoustic change to processing it as a linguistically relevant one.

Based on the findings that training improves both behavioural and neurophysiological discrimination, Tremblay et al. (1998) set out to determine the time course of changes at both levels. In order to do so, participants were tested and trained several times over a period of 10 days (refer to methodology described for Tremblay et al., 1997). The results of the analysis revealed that participants had a slightly different time course with respect to their learning of the contrasts. On the one hand, half of the participants showed a significant change in both their performance on the identification task and the MMN after only one training session. On the other hand, half of the participants also showed a significant difference in the MMN after only one training session but significant improvement on the identification task was observed only at a later stage. It should be mentioned that one of these participants had not actually improved significantly on the identification task by the last training session. The results therefore show that changes in neurological response precede changes in behavioural response and that significant changes at the neurophysiological level may transpire without any changes being observed at the behavioural level. The authors conclude that “changes in neural activity occur rapidly during training, and that these changes are later integrated into functional behaviour” (p. 3560). They also raise the question as to why some individuals are able to integrate neural learning into behavioural learning more rapidly than others. As will be discussed later, the present research addresses this question as it will be proposed that language learning experience may enhance this process.

It appears that training not only affects the MMN but it also incurs changes in other electrophysiological responses such as the N1-P2 complex. While the MMN is believed to reflect sensory discrimination, the P1, N1 and P2 components, which are part of the N1-P2 complex, are thought to signal sensory encoding and detection (Sharma & Dorman, 1999; Tremblay & Kraus, 2002). In their pre-test – post-test data, Tremblay & Kraus (2002) noticed that, after several sessions of training (same method as Tremblay et al., 1997; 1998), the amplitude of N1 and P2 had increased and the amplitude of P1 had decreased. They also observed that while the change in amplitude for P2 was bilateral, the change in amplitude for N1 and P1 was only detected in the midline and right hemisphere electrode sites. Reflecting on these findings and how they relate to previous findings on the effect of training on the MMN (Tremblay et al., 1997), Tremblay & Kraus (2002) conclude that the different neurophysiological changes which result from training signal changes in different perceptual processes. Whereas changes in the MMN is usually interpreted as indicating an enhanced ability to detect the difference between two sounds, the authors suggest that the changes in amplitude in the N1-P2 complex may reflect enhanced perception of the acoustic details in a sound post training. It is also interesting to note that while previous studies have observed a relationship between changes in the MMN and changes in discrimination abilities at the behavioural level (Tremblay et al., 1997; 1998), Tremblay & Kraus (2002) were unable to establish a relationship between changes in the N1-P2 complex and behavioural performance.

The results of behavioural and electrophysiological experiments on the effect of training are also corroborated by fMRI studies. Studies have shown that changes in the pattern of brain

activation are observed after training on the discrimination a non-native contrast is received (Callan et al., 2003; Golestani & Zatorre, 2004).

2.1.3.2 Learning

As mentioned earlier, changes in behavioural and neurophysiological discrimination can transpire with very little training (Tremblay et al., 1998). In fact, research conducted by Näätänen and his colleagues (Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993) has shown that, even without explicit training, changes can be observed at both levels as the amount of exposure to the stimuli increases throughout the same experiment. Using an oddball paradigm during which two different sequences of tones served as standard and deviant, the authors measured behavioural and neurophysiological discrimination at the beginning (early phase), middle (middle phase) and the end (later phase) of an experiment. Each phase consisted of six blocks of 200 stimuli and lasted about 30 minutes. Behavioural (i.e. an oddball discrimination task) and neurophysiological (i.e. an MMN experiment) measures of discrimination were taken following each phase. For the purpose of the analysis, two types of individuals were identified. On the one hand, individuals who showed improvement on the discrimination task from the early phase to the later phase were labelled “improvers”. On the other hand, individuals who performed well on the discrimination task right from the early phase of the experiment and therefore did not show improvement (possibly due to a ceiling effect) were labelled “good non improvers”. The results of the ERP experiment found evidence of learning for both groups of participants from the early phase to the later phase of the experiment. While an increase in the amplitude of the MMN was observed for the group of “improvers”, the latency of the MMN decreased for the group of “good non-improvers. Both an increase in amplitude and

a decrease in the MMN latency have been identified as signs of enhanced discrimination in other studies (Dehaene-Lambertz et al., 2005; Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993; Tremblay et al., 1997). The results of this experiment indicate that, given enough exposure to the stimuli, auditory discrimination can improve without specific training.

2.1.4 The Relationship Between Behavioural and Neurophysiological Responses

While a number of experiments in the field of speech perception have combined both behavioural and neurophysiological methods, the relationship between the two levels of sound discrimination is still not fully understood. While some researchers seem to have been able to establish a correlation between behavioural and neurophysiological sound discrimination (Dehaene-Lambertz et al., 2005; Lang et al., 1990; Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993; Sharma & Dorman, 1999; Tampas et al., 2005), others have not (Dalebout & Stack, 1999; Pettigrew et al., 2004; Shafer et al., 2004).

In their experiments investigating across and within phonetic category discrimination, for instance, Sharma & Dorman (1999) did find a correlation between discrimination rates on an AX task and neurophysiological responses. In this experiment, native speakers of English showed higher rates of discrimination for a pair of sounds which they identified as belonging to two different phonemic categories (i.e. [t] with a VOT of 30 ms vs. [t^h] with a VOT of 50 ms) compared to a pair of sound which they identified as belonging to the same phonemic category (i.e. [t^h] with a VOT of 60 ms and 80 ms). Furthermore, the results of the ERP experiment indicated that the amplitude of the MMN was larger for the across category sound change compared to the within category one. The results therefore indicate

that there may be a relationship between behavioural discrimination abilities and the amplitude of the MMN.

Tampas et al. (2005) found a different type of correlation between behavioural and neurophysiological discrimination. The results of their experiment indicate that both an MMN and a P300 were observed for participants who showed good behavioural discrimination (i.e. oddball discrimination and same/different task) for a non-speech glide contrast (i.e. frequency glide mimicking a CV sequence). Nevertheless, the authors only found a correlation between discrimination abilities on the oddball discrimination task and the P300. Participants who were better at discriminating the glide contrast showed an earlier P300. No such correlation was found between the same/different task and the P300. Also, no correlation was found between the MMN and either type of behavioural responses either. Tampas et al. (2005) conclude that the P300 is therefore a better indicator of behavioural discrimination performance than the MMN. It is also important to note that Tampas et al. (2005) also detected a P300 for the within category speech contrast (i.e. two synthesised CV along a frequency continuum, both categorised as /ba/), which was not discriminated behaviourally. The authors attributed this to a possible effect of learning or training (Tampas et al., 2005). These results are somewhat unexpected since the P300 has been considered to signal conscious discrimination (Dalebout & Stack, 1999).

Other experiments have also failed to find support for the claim that the MMN is a correlate of behavioural discrimination. On the one hand, Pettigrew et al. (2004) found no robust MMN to a speech contrast (/del/ vs. /geɪ/) although it was accurately discriminated behaviourally. Similarly, Dalebout & Stack (1999) did not systematically find an MMN for

an easily discriminated contrast (i.e. /da/ vs. /ga/). It is important, however, to interpret these results with caution since methodological factors may have played a role. First of all, Pettigrew et al. (2004) used real words (i.e. “day” and “gay”) and this may have had an impact on the processing of the stimuli. As for Dalebout & Stack (1999), their MMN results are based on the potentials recorded at Fz only. As discussed earlier, a greater number of channels may have yielded different results. On the other hand, other experiments have reported an MMN for acoustic differences that were not behaviourally discriminated. As mentioned earlier, Rivera-Gaxiola et al. (2000) observed an MMN for the non-native Hindi dental/retroflex contrast in English-speaking adults even though they were unable to discriminate this contrast behaviourally. These results should not, however, be interpreted as evidence for a lack of relationship between behavioural and neurophysiological responses since research has also shown that neurophysiological discrimination may precede behavioural discrimination (Tremblay et al., 1998).

2.1.5 Individual Differences

Although the body of research on speech perception made it possible to identify general patterns of behavioural and neurophysiological discrimination, it is important to point out that considerable individual differences have also been observed (Cowan et al, 1993; Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993). In research investigating the development of memory traces, Näätänen and his colleagues (Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993) observed different patterns of behavioural and neurophysiological sound discrimination among individual participants. Participants were divided into three groups based on their behavioural performance on an oddball discrimination task: (1) improvers: started off as poor discriminators and improved

from session to session; (2) poor non-improvers: started off as poor discriminators and did not show improvement from session to session; and (3) good non-improvers: started off as good discriminators and did not show improvement from session to session. When the neurophysiological discrimination of these groups of participants was compared, differences in the amplitude and latency of the MMN were also identified. On the one hand, the amplitude of the MMN measured for the “improvers” increased significantly from the earlier session to the later session. On the other hand, while the amplitude of the MMN measured for the “good non-improvers” did not increase, the latency of the neurophysiological response decreased. As for the “poor non-improvers”, no change in neurophysiological response was observed (Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993).

Tremblay et al. (1998), who tracked the behavioural and neurophysiological changes in discrimination abilities over a 10 day period during which participants received training, also found important individual differences among their participants. Whereas the changes in neurophysiological responses were significant for all 10 participants after only one training session, participants differed in the number of training sessions required for the integration of neural learning to translate into behavioural learning. The fastest learners improved on the identification task after the first training session, slower learners after two, three or four training sessions and one participant did not show any behavioural learning even after the final training session.

It is interesting to note that developmental studies have also shown that electrophysiological patterns of sound discrimination are highly variable among infants. A

study by Rivera-Gaxiola et al. (2005) revealed that, at 7 and 11 months, discrimination of both native and non-native contrasts is signalled by either a positive (peaking around 150-250ms) or negative deflection (peaking around 250-550ms). Unfortunately, it is still unclear how early electrophysiological patterns of sound discrimination affect later development of speech perception.

Clearly, the process involved in the development of new memory traces for complex sounds varies among individuals, both in terms of initial discrimination responses and in terms of the learning time course. Put together, the experiments conducted by Näätänen and his colleagues (Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993) and Tremblay and her colleagues (Tremblay et al., 1998) highlight individual differences both in terms of neurophysiological learning and in terms of the rate at which neurophysiological learning are observed at the behavioural level. The question that arises then is why some individuals are better at creating a representation for new complex sounds than others. In the following sections, the effect that language learning experience has on various cognitive abilities will be reviewed in an attempt to motivate the hypothesis that having learned more than one language may have an effect on the ability to encode representations of sounds when learning to discriminate a new contrast.

2.2 Effects of Language Learning Experience

2.2.1 Multilingualism and General Cognitive Abilities

Various studies comparing monolinguals, bilinguals and multilinguals have found that individuals with different amounts of language learning experience differ in several respects. Researchers have identified various factors that have an impact on the skills

involved in foreign language acquisition. Prior language learning experience, that is the experience learners have had with learning languages, seems to have a major impact on the way they approach the learning of a foreign language. It is believed that learning an L2 has positive effects on the cognitive development of an individual (Cenoz & Genesee, 1998). Some argue that bilinguals are better language learners than their monolingual counterparts because:

how to learn to learn a language or how to acquire the skills needed for the development of another language system, is one of the factors which due to prior experience with the second language learning process must be considered as developed at a higher level in third language learners than in second language learners. (Herdina & Jessner, 2000, p.92-93)

Studies have demonstrated that, among the skills and cognitive abilities which are enhanced by the process of L2 acquisition and which seem to contribute positively to the acquisition of an additional language are metalinguistic awareness (Cenoz & Valencia, 1994; Dagenais & Day, 1998; Thomas, 1988), information-processing skills (Nation & McLaughlin, 1986), effective use of learning strategies (Abraham & Vann, 1987; Marion & Ramsay, 1980; Nayak et al., 1990; Vann & Abraham, 1990), communication strategies (Thomas, 1992), communicative competence (Ben-Zeev, 1977), and positive attitudes toward language learning (Brohy, 2001).

Most studies in the field of third language (L3) acquisition and multilingualism agree on the fact that, as a result of its positive effects on the individual's cognitive abilities, prior language learning experience does have an impact on the way learners approach the acquisition of an additional language.

2.2.2 Multilingualism and Behavioural Studies of Speech Perception

While a growing number of researchers are finding an interest in the study of the acquisition of non-native languages beyond the L2, most studies to date have been concerned with the acquisition of the lexicon, syntax or with the social aspect of language acquisition, giving considerably less attention to the acquisition of the phonological system. Moreover, among the studies on the acquisition of the sound system in an L3, some have focused on production (Hammarberg & Hammarberg, 1993; Hammarberg & Williams, 1993; Pyun, 2000; Tremblay, under review) and very few have focused on perception (Gallardo del Puerto, 2007). As a result, very little is known about the acquisition of the sound system in an L3 and about speech perception in individuals who have acquired more than two languages.

Since language learning experience has a major impact on various aspects of language acquisition and cognitive abilities, it would not be surprising if monolinguals, bilinguals and multilinguals differed with respect to the way they perceive speech. Thanks to their extensive experience as language learners, bilinguals and multilinguals may be better at perceiving phonetic details, even those that are not relevant for distinguishing meaning in their L1. Viewed in terms of mode of speech processing, it could be argued that monolinguals, bilinguals and multilinguals process sounds at a different level. As opposed to monolinguals, bilinguals and multilinguals may be able to switch more easily from processing speech in a phonetic mode to processing speech in an auditory mode in a non-native language. It could be the case that having already had the experience of learning a non-native language increases an individual's awareness of the importance of paying attention to phonetic details even when such details are not normally attended to in the L1.

Since being able to correctly assess the acoustic characteristic of sounds may be essential to the creation of accurate phonetic categories, it could be argued that bilingual's and multilingual's ability to process speech at an auditory level contributes to greater success in the acquisition of a new phonological system.

Very few studies have compared the perceptual abilities of monolinguals, bilinguals and multilinguals. Moreover, the results of these studies are often contradictory with some suggesting that bilinguals and multilinguals do have better perceptual abilities than monolinguals and other finding no difference at all between these populations. As a result, it is impossible to come to any clear conclusion regarding this issue.

Among the first studies to probe the question is that of Davine et al. (1971). Their study, which compares grade 3 and 4 children who were receiving monolingual and bilingual instruction, reveals no significant differences between monolingual and bilingual children with respect to their ability to discriminate phoneme sequences. The results should nevertheless be interpreted with care due to the method used by the researchers. An ABCX discrimination task with an ISI of 2 seconds between A, B and C and 5 seconds between C and X is likely to have made the level of processing difficulty very high. Moreover, the task involved the discrimination of phoneme sequences as opposed to single segments. As Davine et al. (1971) point out, their findings differ from those of an earlier study by Rabinovitch & Parver (1966, cited in Davine et al., 1971) that suggests that bilinguals are better than monolinguals at discriminating non-native phoneme sequences.

Werker (1986) also investigated the perceptual abilities of individuals with a different learning background. In her study comparing adult monolinguals and adult bilinguals/trilinguals on their ability to discriminate a Salish and a Hindi contrast (i.e. voiceless glottalised velar/uvular stop and voiceless dental/retroflex stop respectively), she asks the question as to whether extensive linguistic experience, as in the case of multilinguals, is enough to enhance perceptual sensitivity or if specific experience is necessary to maintain the ability to perceive a contrast. Since no significant difference between the monolinguals and the multilinguals are found, Werker (1986) concludes that general language learning experience does not help maintain the perceptual flexibility required to discriminate phonetic contrasts without any experience. As pointed out by Werker (1986), however, the results only indicate that monolinguals and multilinguals do not differ with respect to their initial ability to discriminate these non-native phonemes. It would therefore be interesting to test whether these two populations differ in their ability to learn to discriminate these contrasts (Werker, 1986). This could be done by examining the possible changes in discrimination abilities before and after monolinguals and multilinguals are trained on a non-native contrast.

Enomoto (1994), on the other hand, did find an advantage for multilinguals over monolinguals with respect to the discrimination of Japanese singleton versus geminate stops, suggesting that more extensive language learning experience enhances perceptual sensitivity. The author was also interested in determining whether differences can be found among multilinguals based on their experience with languages that have a sound system in which segmental duration is distinguished either allophonically or phonemically. The analysis reveals no significant difference between these two types of multilinguals

suggesting that exposure to multiple languages enhance discrimination abilities of non-native contrasts, regardless of the nature of the sound system of the languages learned (Enomoto, 1994).

More recently, Gallardo del Puerto (2007) also investigated differences in perceptual abilities among different groups of multilingual primary and secondary school children. Based on findings suggesting that the cognitive advantages linked to bilingualism increase with level of proficiency (Cenoz, 2003, cited in Gallardo del Puerto, 2007), the author asks the question as to whether more balanced Spanish-Basque bilinguals would perform better on an English phoneme discrimination task than less balanced bilinguals. The results show that the level of bilingualism has no effect on the participants' ability to discriminate the contrasts. Gallardo del Puerto (2007) concludes, as was suggested by Cenoz (2003), that while the level of proficiency achieved by bilinguals may affect the overall proficiency in the L3, specific aspects such as speech perception may not be affected directly. While it is impossible to determine how the performance of these bilingual children compares to that of same age monolingual children, the results of this study could be interpreted as indicating that language learning experience has a similar effect on speech perception abilities regardless of the level of proficiency achieved in the L2.

2.2.3 Neurophysiological Evidence of the Effect of Language Learning Experience on Speech Perception

In addition to approaching the question as to whether language learning experience affects speech perception from the perspective of mode of speech processing, it is also relevant to

ask whether such effect could be observed at the level of neural processing. To date, no study has addressed this issue from a neurophysiological perspective.

As illustrated by the various experiments reviewed above, there are several advantages for relying on neurophysiological methods. First of all, the MMN is a pre-attentive measure of discrimination that does not depend on the performance of the individual on a given task or, for that matter, does not even require the individual to pay attention to stimulation. The MMN is therefore a relatively objective measure of discrimination abilities (Alho & Sinervo, 1997; Näätänen et al., 1982, in Näätänen, 2001, p. 5) at least more objective than other types of measures that are more influenced by voluntary processes (Näätänen & Winkler, 1999). Moreover, changes in discrimination abilities at the neurophysiological level can be incurred before or even without indication of such changes at the behavioural level (Tremblay et al., 1998; Tremblay & Kraus, 2002). Finally, as Näätänen & Winkler (1999) mention, “ERP components (like the MMN) may directly reflect specific brain functions, whereas most behavioural measures show the final common outcome of a complex set of processes and, therefore, can be used only as indirect indexes of the process(es) of interest” (p. 849). The MMN provides very important information about the timing, the amplitude and the location on the surface of the scalp of the electrophysiological activity generated by a sound change. This not only makes it possible to determine whether a contrast is discriminated, but also potentially at what level (i.e. acoustically vs. phonetically).

It could be argued that the lack of success of previous studies in obtaining a clear idea of whether language learning experience affects speech perception partly stems from the fact

that behavioural methods were simply not precise and thorough enough to detect differences between monolinguals, bilinguals and multilingual given that the differences are potentially not only in the outcome of behavioural discrimination but also in the process itself. Nevertheless, it seems important not to rely solely on neurophysiological methods but rather to combine them with behavioural methods if the issue is to be fully investigated. Besides, research has shown that there is often a correlation between neurophysiological and behavioural discrimination (Sharma & Dorman, 1999; Tampas et al., 2005) and that behavioural discrimination is sometimes apparent without clear evidence of discrimination at the neurophysiological level (Dalebout & Stack, 1999; Näätänen & Winkler, 1999).

2.3 Summary and Conclusions

It is clear from the body of literature that the ability to detect changes across phonemic boundaries that are not active in one's native language is not fully lost (Zhang et al., 2005). The studies just reviewed show that, as the amount of exposure increases or with as little as one training session, adults can improve both their behavioural and neurophysiological discrimination abilities for complex sounds and non-native contrasts. Following training, adults can display an MMN to non-native contrasts, suggesting that the brain does not completely lose its plasticity and that memory traces can be developed in order to encode new phonetic representations (Tremblay et al., 1997; Tremblay et al., 1998; Zhang & Wang, 2007). Over a period of time, the effect of training is manifested by an increase in the duration and area of the MMN as well as a decrease in the onset latency of this MMN (Tremblay et al., 1997; Tremblay et al., 1998). Since learning to perceive new phonetic contrasts implies the development of new memory traces in the auditory cortex, these studies therefore provide evidence that brain plasticity is not completely lost in adulthood

(Näätänen, 2001; Tremblay et al., 1997). As research has indicated, not everyone has the same potential to develop the ability to discriminate new non-native contrasts (Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993; Tremblay et al., 1997; Tremblay et al., 1998). The question then arises as to whether this potential depends on the extent to which the individual's brain has retained the level of brain plasticity required for the development of new memory traces. An important body of research focusing on the effects of language learning experience on various cognitive abilities has confirmed that learning more than one language is beneficial in several respects. It is therefore reasonable to hypothesise that language learning experience may contribute to the maintenance of greater brain plasticity which in turn contributes to the learning of new phonological contrasts. Since a sound change that is perceived at the acoustic level relies on different resources in the brain compared to a sound change that is perceived at the phonetic level, not only will it be possible to determine whether monolinguals, bilinguals and multilinguals differ in terms of whether or not they can detect a change in stimuli, but also if they differ in terms of whether they perceive the sound change as a linguistically meaningful difference or a simple acoustic difference.

The number of studies focusing on the perceptual abilities of multilinguals is extremely limited. As a result, little is known about how language learning experience affects perceptual sensitivity. The fact that these studies target different populations and differ in terms of their methods makes it difficult to compare their results. It is also conceivable that the contradictions regarding the superior perceptual abilities of multilinguals over monolinguals are due to the fact that these behavioural studies were designed, although not purposefully, to probe different levels of speech processing. Moreover, the finding that

neurophysiological responses are not always corroborated at the behavioural level raises the question as to whether differences between monolinguals and multilinguals would be more reliably found by combining both behavioural and electrophysiological methods. Lastly, it is possible that while initial discrimination abilities are not affected by language learning experience, that the ability to learn to discriminate a new contrast as a result of training may be. The proposed study will therefore contribute greatly to the fields of multilingualism and speech perception as it will not only provide more insight into how more experienced language learners differ from less experienced ones in terms of perceptual abilities, but it will also rely on a more thorough methodology to do so.

Chapter 3 – Methodology

3.1 Aim of the Study

The aim of the study is to determine whether monolinguals, bilinguals and multilinguals process speech sounds in the same way or whether perceptual sensitivity increases as a function of language learning experience. More specifically, the goal is to determine whether the same behavioural and neurophysiological responses are elicited when these different populations are presented with a phonological contrast that is not found in any of the languages they have been exposed to. Moreover, this study is concerned with the effect of language learning experience on learning abilities. In other words, the aim is to determine whether monolinguals, bilinguals and multilinguals respond to a small amount of training on the discrimination of a non-native contrast in the same way. Finally, an attempt is made to determine whether these groups of individuals differ in their ability to transfer the training received on a contrast to a different but similar contrast.

3.2 Research Questions

The specific research questions addressed by the study are the following:

(1) Do monolinguals, late bilinguals, early bilinguals and multilinguals differ with respect to their ability to discriminate a non-native contrast at the behavioural level? Are there differences between these groups in terms of accuracy rate and reaction time on an AX discrimination task?

(2) Do monolinguals, late bilinguals, early bilinguals and multilinguals differ with respect to their ability to discriminate a non-native contrast at the neurophysiological level? Are there differences between these groups in terms of the amplitude and typology of the MMN?

(3) Is the effect of language learning experience noticeable:

- upon first exposure to a non-native contrast?
- after receiving a small amount of training on the discrimination of a non-native contrast?
- when exposed to a contrast that is different but similar to the one on which they have received a small amount of training?

3.3 Hypotheses

Overall, it is hypothesised that perceptual sensitivity and learning abilities increase with the number of languages learned such that multilinguals are predicted to be better than bilinguals who are predicted to be better than monolinguals. With respect to the age of acquisition of the L2, it is unclear whether having learned two languages from birth would be advantageous compared to having learned an L2 later. Nevertheless, since these two types of learners are believed to process language differently in other areas of language (Stowe & Sabourin, 2005), both groups will be tested separately.

With respect to behavioural discrimination at Pre-Test, it is difficult to make any hypotheses on whether group differences will be detected before training since studies have been inconclusive with respect to initial discrimination abilities. At Post-Test, it is

hypothesised that differences between the groups will be found after the participants have been trained on the non-native contrast. This should be reflected by greater accuracy rates for more experienced language learners at Post-Test. Based on a study by Shafer et al. (2004) which has shown that reaction times can also be a measure of discrimination abilities, it is expected that more experienced language learners will provide faster responses as well. It is also hypothesised that the ability to transfer what is learned to a new but similar contrast, as evidenced by higher accuracy rates and faster reaction times, will increase as a function of the number of languages learned. These predictions regarding the effect of training on discrimination abilities are based on the claim that more experienced language learners are better language learners (Herdina & Jessner, 2000).

At the level of electrophysiological discrimination, it is hypothesised that differences will be found both before and after the participants receive training on the discrimination of the contrast as well as for the new but similar contrast. This hypothesis is based on the fact that discrimination at the neurophysiological level precedes discrimination at the behavioural level (Näätänen, 2001). As a result, it is hypothesised that group differences will be observed before training at the neurophysiological level regardless of whether such differences are observed at the behavioural level. Group differences should be reflected by a larger MMN amplitude for more experienced learners. Differences in terms of MMN typology are also expected. Since a larger MMN amplitude on the left side is indicative of an enhanced level of speech processing (Shafer et al., 2004), more experienced language learners are expected to show a larger MMN amplitude on the left side compared to less experienced ones at both testing times.

3.4 Overall Experimental Design and Procedures

3.4.1 Participants

3.4.1.1 Recruiting and Participant Selection

Potential participants were mainly recruited through classroom visits at the University of Ottawa. Individuals who showed an interest were sent an email containing detailed information about what participating in the experiment involved. Those interested were asked to fill out a short questionnaire attached to the email (see Appendix 1 – Recruitment Questionnaire) and to send it back to the experimenter. The answers provided basic information about age, language learning experience and handedness, which allowed the experimenter to determine whether the individual qualified for the experiment.

Individuals between the ages of 18 and 40 years old who identified themselves as a native speaker of either English or English and French were asked to participate in the study.

English was chosen as the main L1 in order to make sure that all participants would have a common native language. Moreover, it appeared to be the most logical choice in terms of availability of the participants. A native speaker of English could either have learned (1) no other language, (2) French as an L2 or as a second L1 and no other language or (3) French as an L2 or as a second L1 and any other language that does not contain the experimental contrast (i.e. dental vs. retroflex; see section on stimuli) in its phonological inventory (see Section 3.4.2.1 for more details on the phonological system of the additional languages learned by the participants). French could have been learned either at the same time as English (i.e. from birth) or later. Once again, French was selected as the common L2 because English-French bilinguals represent the most readily available population in the region of Ottawa and because this ensured that all bilingual and multilingual participants

had at least two languages in common. With respect to the other languages known by the multilingual participants, as mentioned above, any language that does not contain the experimental contrast was permitted. Although it would have been ideal to also have a common L3 for all multilingual participants, it did not appear a viable option in terms of recruiting the number of participants required for the experiment.

For the ERP component of the experiment, handedness was also considered for the selection of the participants. While the language functions are generally lateralised in the left hemisphere for most people, studies have shown that there is more variation in terms of brain organisation among left-handed individuals (Obler & Gjerlow, 1999). As a result, only right-handed individuals took part in the ERP experiment. Left-handed individuals who still wished to participate in the study were asked to take part in the behavioural experiment only (i.e. AX discrimination task and identification task). Participant E026 is the only left-handed individual who participated in the experiment.

Finally, at the beginning of the first session, participants were required to pass a hearing screening at 30 dBHL at 0.5, 1, 2 and 4 kHz bilaterally. A Maico MA27 portable audiometer was used for the screening. All of the participants passed the screening.

3.4.1.2 Groups

Before starting the experiment, participants were asked to fill out a language background questionnaire (see Appendix 2 – Background Questionnaire) that inquired about the languages learned, the order and age of acquisition, the percentages of use in a variety of daily situations and self-assessments of the level of oral and written proficiency in each

language. When necessary, the experimenter asked further questions about the languages learned in order to determine, with more precision, the level of proficiency (e.g. Could you hold a conversation in this language? Do you find it easier to communicate in English or in French? etc.). The proficiency level in the languages learned was not tested for two reasons. First of all, self-reports on level of proficiency tend to be correlated with actual level of proficiency (Marian et al., 2007). Furthermore, level of bilingual proficiency (bilinguals who are balanced vs. less proficient) does not seem to have a major impact on speech perception in an additional language (Gallardo del Puerto, 2007).

Based on their language learning background, participants were divided into the following six groups (for more details, see Appendix 3 – Participants Information):

- Control: Participants in this group were exposed to English since birth and have native competence in this language. Exposure and level of proficiency in additional languages varies. Participants in this group were tested at Pre-Test and Post-Test in the same way as the other groups. However, they did not participate in any of the training sessions.
- Monolingual: Participants in this group have all been exposed to English from birth and have native proficiency in this language. Most of them have also been exposed to French and, in some cases, to other languages, but, according to self-report, they have low or very low proficiency in these languages.
- Late Bilingual: Participants in this group were exposed to English from birth and have native proficiency in this language. They have been exposed to French no earlier than 3

years of age and have intermediate/advanced, near-native or native competence in French. They have all been exposed to French in a formal setting (i.e. in school) and none of them lived in a French speaking environment. Some of them have also been exposed to other languages, but, according to self-report, they have low/intermediate to very low proficiency in these languages.

- Early Bilingual: Participants in this group were exposed to English from birth and have native competence in this language. They were all exposed to French at home from birth, except for participant E036, who was exposed to French at the age of 2 in a French-English bilingual preschool environment. They have intermediate/advanced, near-native or native competence in French. Some of them have also been exposed to other languages, but, according to self-report, they have low/intermediate to very low proficiency in these languages.

- Multilingual: Participants in this group were exposed to English from birth and have native competence in this language. They may have been exposed to French from birth or later in life and have intermediate/advanced, near-native or native competence in this language. They were also exposed to at least one additional language from birth or later in life and have intermediate/advanced, near-native or native competence in this language.

3.4.2 Stimuli

3.4.2.1 Choice of Contrasts

Three different contrasts were needed for the present experiment. First of all, a native contrast (i.e. contrast found in the native language of the participants) was selected as a “control” contrast. Including such a contrast serves an important purpose since it helps to determine that the experiment is well designed and, in the case of the behavioural tasks, that the participant understands the task. The contrast selected for the experiment is the voiceless aspirated bilabial vs. velar stops (i.e. English /p/ and /k/).

Two non-native contrasts were also selected for the experiment. The two contrasts serve different purposes. On the one hand, the “experimental” contrast is the contrast on which participants are tested before and after they receive training on the contrast. On the other hand, the “transfer” contrast is the contrast on which participants are tested only at Post-Test, without receiving any training on it. The two contrasts will help determine whether participants with different language learning background can apply the training they have received on one contrast (i.e. experimental) to the discrimination of this contrast and of a different but similar contrast (i.e. transfer).

Perception experiments have demonstrated that not all contrasts are equal with respect to their perceptual salience (Best & McRoberts, 2003; Werker, 1994). As a result, the selection of these contrasts is very important. Since the dental/retroflex stop contrast has been proven to be fairly difficult to discriminate for both English and French speakers, both behaviourally (English: Pruitt et al., 2006; Werker, 1986; Werker & Tees, 1984a, b; French: Dehaene-Lambertz, 1997) and neurophysiologically (English: Golestani & Zatorre,

2004; French: Dehaene-Lambertz, 1997), it was a good candidate for the present study¹. This difference in place of articulation, which is contrastive in languages such as Hindi, Urdu and Bengali (i.e. substituting a dental stop for a retroflex stop can potentially change the meaning of a word), is not contrastive in English and French (i.e. substituting a dental stop for a retroflex stop does not change the meaning for a word). It is important to note, however, that both sounds have been attested in English (Pruitt et al., 2006). While the English /t/ and /d/ are typically considered to be alveolar, they are occasionally realised as either a dental or a retroflex in certain environments (e.g. /d/ and /t/ can be retroflex when preceded by /r/ as in “dry” and “try”, Pruitt et al., 2006). It is important to stress the fact, however, that this variation is strictly allophonic in English. It should also be noted that while /t/ and /d/ are generally considered to be dental in French, their retroflex counterparts are not generally attested in this language. Retroflex stops are occasionally observed in some English loan words produced by some French speakers who also know English (e.g. *Dirty Dancing*) (MC Séguin, personal communication). Nevertheless, not only is the use of this variant restricted to loan words, but it also appears in free variation with the French dental stop and is therefore not contrastive. It is safe to conclude that the dental/retroflex contrast is not a contrast to which speakers of English and French are significantly exposed. For this reason, it is considered that the dental/retroflex contrast is a non-native contrast for all of the participants in the experiment.

Although Enomoto (1994) found no difference in terms of discrimination abilities between multilinguals who had experience with a language that had the same type of contrast as the

¹ Since Native speakers of French have difficulty with the dental/retroflex contrast even though French has a dental stop (Dehaene-Lambertz, 1997), the fact that French was selected as the L2 of the participants was not expected to give them any advantage with respect to the discrimination of the dental/retroflex contrast.

one being tested compared to those who did not, the phonological system of the languages learned by the multilinguals was nevertheless taken into consideration in order to ensure that these languages did not contain the contrasts tested in the experiment. As can be seen in the table for the multilinguals in Appendix 3, the additional languages learned by the multilinguals are German, Japanese, Mandarin, Spanish and Vietnamese. First of all, Spanish has a dental stop, but not retroflex stop. As for German, it has an alveolar stop, but no retroflex. Mandarin has a dental/retroflex contrast, but for affricates and fricatives only. Vietnamese also has a dental/retroflex contrast for fricatives. With respect to Japanese, as mentioned in Pruitt et al. (2006), this language contrasts a voiced alveolar stop (/d/) and the /r/ which is sometimes produced as a voiced retroflex flap/tap. Nevertheless, this contrast is not found for the voiceless aspirated nor the voiceless unaspirated context, which are the two contrasts involved in this experiment. Vietnamese has a dental/retroflex contrast for fricatives, but not for stops. Formal Southern Vietnamese has a retroflex affricate, but it is the only affricate in the phonological system (Marc Brunelle, personal communication).

Another advantage for using this contrast is the fact that, in oral stops, this difference in place of articulation is found for four different types of voicing/aspiration contexts (i.e. voiced unaspirated, voiced aspirated, voiceless unaspirated and voiceless aspirated). This makes it a great candidate for our experimental-transfer pair of contrasts. Whereas the voiceless aspirated dental vs. retroflex contrast (i.e. /t/ vs. /t/) was selected as the experimental contrast, the voiceless unaspirated dental vs. retroflex contrast (i.e. /d/ vs. /d/) was selected as the transfer contrast.

3.4.2.2 Nature of the Stimuli

Since any acoustic changes in the stimuli could trigger an MMN, synthetic stimuli are often preferred in neurophysiological speech perception experiments (Dehaene-Lambertz, 1997; Sharma & Dorman, 1999; Tremblay et al., 1997; Winkler, Lehtokoski et al, 1999). In an attempt to make the experiment as linguistically relevant as possible, however, natural speech was used to create the stimuli. Moreover, the set of stimuli consist of several tokens of each type of sound. Doing so forces participants to overlook within-category variability while focussing on differences across categories (Pruitt et al., 2006; Werker & Lalonde, 1988).

3.4.2.3 Control Contrast

As mentioned above, the control contrast in this experiment is the voiceless aspirated bilabial vs. velar stop (i.e. English /p/ and /k/). The stimuli were recorded by a 21-year-old male native speaker of English from the city of Ottawa. The recordings were made in a sound treated room in the phonetics laboratory at the University of Ottawa using a Marantz PMD 660 digital recorder and a Shure SM10A microphone. This male speaker was asked to repeat the syllables /pa/ and /ka/ several times. A total of four tokens were selected for use in the experiment: two for the voiceless aspirated bilabial stop and two for the voiceless aspirated velar stop. The tokens were selected on the basis that they were similar in terms of duration, VOT (within category) and syllable duration. VOT and vowel duration were measured for each stimulus selected for the present study using Praat (version 5.0.25; Boersma & Weenink; 2008) (see Appendix 4 – Stimuli Information). The intensity for each stimulus was equated to 70 dB using Praat.

3.4.2.4 Experimental Contrast

All of the recordings that make up the stimuli used for the experimental (and transfer contrast) were selected from a wider set of stimuli provided by John Pruitt (Pruitt, 1996; Pruitt et al., 2006). The stimuli were all recorded by the same individual, a 23-year-old male native speaker of Hindi (Pruitt et al., 2006). He was born and raised in India, but had been living in the United States for a period of 3 years at the time of the recordings. A more detailed description of the stimuli, recording equipment and procedures can be found in Pruitt (1996) and Pruitt et al. (2006). The stimuli used to test the experimental contrast consist of single syllables (CV) with the voiceless aspirated dental and retroflex stops as the onset followed by the vowel /a/ (Pruitt, 1996; Pruitt et al., 2006). A total of eight tokens were selected for this part of the experiment: four voiceless aspirated dental stops and four voiceless aspirated retroflex stops. VOT and vowel duration were measured for each stimulus selected for the present study using Praat (see Appendix 4 – Stimuli Information). Finally, for the purpose of this experiment, the intensity for each stimulus was also equated to 70 dB using Praat.

3.4.2.5 Transfer Contrast

The stimuli used to test the transfer contrast consisted of single syllables (CV) with the voiceless unaspirated dental and retroflex stops as the onset followed by the vowel /a/. They were also selected from a wider set of stimuli provided by John Pruitt (Pruitt, 1996; Pruitt et al., 2006). A total of eight tokens were selected for this study: four voiceless unaspirated dental stops and four voiceless unaspirated retroflex stops. The stimuli were all recorded by the same 23-year-old male speaker of Hindi who recorded the experimental contrast (Pruitt et al., 2006). Once again, a more detailed description of the recording

equipment and procedures can be found in Pruitt (1996) and Pruitt et al. (2006). VOT and vowel duration were measured for each stimulus selected for the present study using Praat (see Appendix 4 – Stimuli Information). Finally, for the purpose of this experiment, the intensity for each stimulus was equated to 70 dB also with the help of Praat.

3.4.3 Overall Procedures

The experiment took place in the Psycholinguistics Laboratory in the Department of Linguistics at the University of Ottawa. Participants in the four experimental groups (i.e. monolinguals, late bilinguals, early bilinguals and multilinguals) came in for three sessions with a 4-5 day interval between each session. Participants in the control group only came in for Session 1 and Session 3 at an 8-10 day interval. The procedures for the different sessions will be discussed in the following paragraphs for the experimental groups (Section 3.4.3.1) and for the control group (Section 3.4.3.2). The specific methods and procedures for each type of experiment will be presented in Chapters 4 (Training: Identification Task), 5 (AX Discrimination Task) and 6 (ERP Experiment).

3.4.3.1 Experimental Groups

Session 1 started with the participant signing a consent form (see Appendix 5 – Consent Form). Then, participants filled out the language background questionnaire (see Appendix 2 – Background Questionnaire). This was followed by a hearing screening (see Section 3.4.1.1 on Recruiting and Participants Selection). The experiment then started with the ERP experiment. The first contrast tested was the control contrast. Then, after a short break, the experimental contrast was tested. Once the ERP experiment was over, participants were asked to perform the AX discrimination task for the experimental contrast (i.e. voiceless

aspirated dental vs. retroflex stop). Finally, participants performed the training task. The different components were performed in this order (i.e. ERP before behavioural tasks) in order to minimise the chances that the participants would attend to the stimuli during the collection of ERP data (Winkler et al., 1999). This session lasted on average 2 hours and 30 minutes. Between each part of the experiment, participants were always given the opportunity to take a break if they felt the need to. They were also offered juice and snacks.

Participants came in for Session 2 4-5 days after Session 1. During this session, they performed the training task twice. This session lasted on average 25 minutes.

Session 3 took place 4-5 days after Session 2. Participants were first asked to perform the training task one more time. This was followed by the ERP experiment. The first contrast to be tested was the experimental contrast (i.e. voiceless aspirated dental vs. retroflex stops). Then, after a short break, the transfer contrast was tested (i.e. voiceless unaspirated dental vs. retroflex stop). Once the ERP experiment was over, they were asked to perform an AX discrimination task, first for the experimental contrast, then for the transfer contrast. This session lasted on average 2 hours and 15 minutes. As for Session 1, participants were always given the opportunity to take a break between each part of the experiment if they felt the need to. They were also offered juice and a snack. Table 3.1 provides a summary of the various components of the experiment and the order in which they were performed.

Table 3.1 – The Experiment: Experimental Groups

Session 1	Session 2	Session 3
(1) Consent form, questionnaire and hearing screening	(1) Training: Experimental contrast	(1) Training: Experimental contrast
(2) ERP experiment: Control contrast		(2) ERP experiment: Experimental contrast
(3) ERP experiment: Experimental contrast		(3) ERP experiment: Transfer contrast
(4) AX discrimination task: Experimental contrast		(4) AX discrimination task: Experimental contrast
(5) Training: Experimental contrast		(5) AX discrimination task: Transfer contrast

3.4.3.2 Control Group

The same overall procedures as for the experimental groups applied for the control group except for the following differences. Participants in this group did not perform any of the training sessions. As a result, they only came in for Session1 and Session 3. Session 3 took place 8-10 days after Session 1. The 2 sessions were slightly shorter for this group than for the experimental groups as no training sessions were done (i.e. Session 1: 2 hours and 15 minutes on average; Session 3: 2 hours on average). Table 3.2 provides a summary of the various components of the experiment and the order in which they were performed.

Table 3.2 – The Experiment: Control Group

Session 1	Session 2	Session 3
(1) Consent form, questionnaire and hearing screening		(1) ERP experiment: Experimental contrast
(2) ERP experiment: Control contrast		(2) ERP experiment: Transfer contrast
(3) ERP experiment: Experimental contrast		(3) AX discrimination task: Experimental contrast
(4) AX discrimination task: Experimental contrast		(4) AX discrimination task: Transfer contrast

Chapter 4 – Training: Identification Task

4.1 Method

4.1.1 Participants

A total of 53 participants participated in the training sessions, out of which 50 participants were included in the analysis. It is important to note that participants in the control group did not perform this task. Table 4.1 provides the number of participants in each group (for more details on the participants in each group, see Appendix 3 – Participants Information).

Table 4.1 – Number of Participants for the Identification Task

Group	Monolinguals	Late Bilinguals	Early Bilinguals	Multilinguals
N	13	12	13	12

One participant was excluded from the analysis because he provided too many incorrect responses for the control trials on the AX discrimination task (E037: early bilingual, see Section 5.1.1 for more details). Two participants were excluded because they did not participate in all three sessions (E006: late bilingual; E030: early bilingual).

4.1.2 Procedures

This part of the experiment consisted of a training phase aimed at giving participants the opportunity to improve their discrimination skills on the experimental contrast (voiceless aspirated dental/retroflex stop). The training started with a habituation phase during which the two sounds were played for the participant. First, the voiceless aspirated dental stop was played eight times while the label “t” appeared on the computer screen (white font on black background) (more details about the equipment used are provided in the last paragraph of

this section). Then, the participant was prompted by instructions on the screen to press the spacebar in order to hear the next sound. Then, the voiceless aspirated retroflex stop was played eight times while the label “T” appeared on the screen (white font on black background).

The experimental phase of the training consisted of an identification task. During the identification task, the voiceless aspirated dental and retroflex stops were played randomly and participants were asked to identify which sound they thought they heard. Responses were provided by pressing the “z” key for the dental and the “?” key for the retroflex. A piece of black felt with the labels “t” and “T”, for “dental” and “retroflex” respectively, placed on the keyboard above the keys to be pressed and covering the surrounding keys ensured that the key associated with each response was clearly identified. Feedback was provided on the answers. A green happy face appeared when the answer was correct and a red frowny face appeared when the answer was incorrect. The happy/frowny face appeared on the screen for 2 seconds. It would then disappear and the next trial started 500 ms later. If no response was provided within five seconds of the start of the trial, the trial was terminated and the next trial would start 500 ms thereafter. Before starting the experimental phase (right after the habituation phase) participants performed six practice trials (three dental and three retroflex trials) to ensure that they understood how to perform the task. The practice trials were not included in the analysis.

All training sessions were identical. They all started with the habituation phase, followed by the practice phase and finally the experimental phase. The experimental phase consisted of 160 trials (80 dental and 80 retroflex trials) divided into two blocks with a short break in

between. The two blocks each consisted of 80 trials containing an equal number of trials of each type and trials were randomised within each block for each participant. Participants performed this training task once at Session 1, twice at Session 2 and once at Session 3.

The identification task was designed on Psyscope X B51 (Cohen, J.D. et al., 1993) and was presented on a MacBook Pro running Mac OS X version 10.5.8. Instructions were provided on the computer screen but the experimenter also explained the task verbally. Participants wore an MB Quart K 900 SC headset to listen to the stimuli. The task was performed in a sound attenuated room in the ERPLING Laboratory at the University of Ottawa.

4.1.3 Stimuli

All eight tokens from the voiceless aspirated stop contrast (four dental and four retroflex) were included in this component of the experiment. They each appeared an equal number of times over one session. Participants all performed the same version of this experiment.

4.2 Accuracy Rates

4.2.1 Results

The mean accuracy rate was calculated for each participant by dividing the number of correct responses by the total number of trials for which a response was provided.¹

Accuracy rates for the two identification tasks at Session 2 were averaged together and accuracy rates were calculated for each session (i.e. Session 1, Session 2 and Session 3). A

¹ Two participants did not provide a response to one trial each at Session 1 (E015, E050). Three participants did not provide a response for 2-3 trials each at Session 2 (E024, E034, E041). Three participants did not provide a response for one trial each at Session 3 (E011, E025, E035).

3 (Sessions) x 4 (Groups) x 2 (Stimulus Types) ANOVA was performed on the accuracy rates for the identification task. The results of the analysis are presented in Table 4.2.

Table 4.2 – Session x Group x Stimulus Type ANOVA

Factor	df	F	<i>p</i>
Session	2	15.467	< 0.001***
Group	3	1.304	0.284
Stimulus Type	1	14.287	< 0.001***
Session*Group	6	1.577	0.163
Session*Stimulus type	2	1.438	0.243
Group*Stimulus type	3	0.419	0.740
Session*Group*Stimulus type	6	1.482	0.193

As shown in Table 4.2, the analysis revealed a main effect of Session ($F(2,92) = 15.467$, $p < 0.001$). Pairwise comparisons determined that the mean accuracy rate at Session 1 was significantly lower than the one at Session 2 ($p < 0.001$) and Session 3 ($p < 0.001$). No significant difference was found between Sessions 2 and 3 ($p = 0.11$). Table 4.3 provides the mean accuracy rates, range and standard deviation for each session.

Table 4.3 – Accuracy Rates (in %) for each Session

Test	N	Mean	Range	SD
Session 1	50	81.5	54.1 – 98.1	10.4
Session 2	50	86	62.1 – 97.5	8.7
Session 3	50	87.4	55.6 – 100	10.4

A main effect of Stimulus Type was also found ($F(1,46) = 14.287$, $p < 0.001$). As Table 4.4 shows, “dental” trials were identified with more accuracy than “retroflex” trials.

Table 4.4 – Accuracy Rates (in %) for each Stimulus Type

Stimulus Type	N	Mean	Range	SD
Dental	50	87.4	59 - 98	8.6
Retroflex	50	82.7	57 - 99	10.7

Neither the main effect of Group ($F(3,46) = 1.304, p = 0.284$), nor any of the interactions involving this factor turned out as significant (Session*Group: $F(6,92) = 1.577, p = 0.163$; Group*Stimulus Type: $F(3,46) = 0.419, p = 0.740$; Session*Group*Stimulus Type: $F(6,92) = 1.482, p = 0.193$). Nevertheless, based on the hypothesis that language learning experience may affect speech perception, the following analyses were performed in order to fully investigate this issue. First of all, three separate One-Way ANOVAs were performed on the accuracy rates at Session 1, Session 2 and Session 3 with Group as factor in order to confirm that the different groups did not perform differently at each training session. None of them turned out to be significant (Session 1: $F(3,49) = 0.996, p = 0.403$; Session 2: $F(3,49) = 1.374, p = 0.262$; Session 3: $F(3,49) = 1.75, p = 0.17$). A separate repeated measures ANOVA was also performed on the accuracy rates for each group with Session as factor. A main effect of Session was found for all of the groups except for early bilinguals. For the monolingual group ($F(2,24) = 6.343, p = 0.006$), pairwise comparisons indicate that accuracy rates at Session 3 were significantly higher than at Session 1 ($p = 0.003$) and Session 2 ($p = 0.05$) (Table 4.5).

Table 4.5 – Accuracy Rates (in %) for Monolinguals at each Session

Test	N	Mean	Range	SD
Session 1	13	85.2	69.4 – 97.5	8.2
Session 2	13	87.1	77.1 – 97.5	7.4
Session 3	13	89.6	75 – 98.6	7.7

The analysis also revealed a significant effect of Session for the late bilinguals ($F(2,22) = 10.194, p = 0.001$). Pairwise comparisons indicate that performance improved significantly from session to session (1 vs. 2: $p = 0.011$; 1 vs. 3: $p = 0.006$; 2 vs. 3: $p = 0.028$) (Table 4.6).

Table 4.6 – Accuracy Rates (in %) for Late Bilinguals at each Session

Test	N	Mean	Range	SD
Session 1	12	78.4	54.1 – 95.6	9.7
Session 2	12	85.9	75.6 – 97.5	5.7
Session 3	12	88.4	79.4 – 100	5.6

The analysis also revealed a significant effect of Session for the multilingual group ($F(2,22) = 6.252, p = 0.01$). Pairwise comparisons indicate that accuracy rates at Session 1 are significantly lower than at Session 2 ($p = 0.006$) and Session 3 ($p = 0.027$) (Table 4.7).

Table 4.7 – Accuracy Rates (in %) for Multilinguals at each Session

Test	N	Mean	Range	SD
Session 1	12	82.2	58.7 – 98.1	12.2
Session 2	12	89.1	62.2 – 97.2	9.7
Session 3	12	90	55.6 – 100	12.3

With respect to the early bilingual group, the results of the analysis show no effect of Session ($F(2,24) = 0.353, p = 0.706$) (Table 4.8).

Table 4.8 – Accuracy Rates (in %) for Early Bilinguals at each Session

Test	N	Mean	Range	SD
Session 1	13	80.1	63.8 – 95.6	11.3
Session 2	13	82.3	62.5 – 96.9	10.7
Session 3	13	82	58.1 – 100	13

4.2.2 Discussion

The results show that participants have an easier time identifying dental trials than retroflex trials. This is not surprising since dental stops resemble closely the alveolar stops found in the native language of the participants while retroflex stops should be unfamiliar for these participants. Moreover, dental stops are found in French, a language to which all of the participants have had some exposure, some more than others.

Group membership did not affect performance on the identification task since neither the main effect of Group, nor any of the interactions involving this factor, was significant. While these results could be interpreted as meaning that language learning experience does not have a significant effect on the ability to correctly identify the two phonemes, the results of the analysis comparing performance at each session for each group suggests otherwise. In general, participants performed better on the identification task at Sessions 2 and 3 than at Session 1. Further analyses revealed that while monolinguals' performance only improved at the third and final session, late bilinguals and multilinguals' performance improved even after only one training session. No effect of Session was found for early bilinguals. These results suggest that language learning experience may affect the ability to identify the dental and retroflex sounds such that late bilinguals and multilinguals need less training than monolinguals and early bilinguals to improve their performance on such a task.

With respect to multilinguals, the results confirm that having learned three languages or more increases the ability to perceive new sounds. The results also suggest that a similar effect is found for late bilinguals. Having learned an L2 later in life may also lead to increased sound learning abilities. No such effect was found however for early bilinguals.

The difference between early and late bilinguals could be interpreted as a difference in terms of context of acquisition. On the one hand, late bilinguals have had to learn French in a formal setting. Perhaps learning an L2 in a more conscious way, through formal training, helped late bilinguals benefit more from formal training on the identification of the new sounds. Early bilinguals, on the other hand, learned two languages in a natural setting, through exposure to both French and English at home (except for participant E036 who was exposed to French in kindergarten). Therefore, these participants were never required to consciously think about new sounds in the same way as late bilinguals have. Finally, monolinguals also showed improvement at Session 3. The fact that monolinguals did improve significantly while early bilinguals did not is to some extent surprising considering that early bilinguals have more experience with learning languages. Again, the results could reflect the fact that having learned two languages in a natural setting does not necessarily translate into a greater ability to learn new sounds in a formal setting. Moreover, it should be noted that while they have only achieved a low level of proficiency in this language, most monolinguals in this study have been exposed to French in a formal setting.

4.3 Reaction Times

4.3.1 Results

The mean Reaction Time (RT) was calculated for each participant for each session (i.e. Session 1, Session 2 and Session 3). Mean RT was based on both correct and incorrect responses. A 3 (Sessions) x 4 (Groups) x 2 (Stimulus Types) ANOVA was performed on the RT for the identification task. The results of the analysis are presented in Table 4.9.

Table 4.9 – Session x Group x Stimulus Type ANOVA

Factor	df	F	p
Session	2	5.428	0.006**
Group	3	1.394	0.257
Stimulus Type	1	8.676	0.005**
Session*Group	6	0.804	0.569
Session*Stimulus type	2	1.429	0.245
Group*Stimulus type	3	1.248	0.303
Session*Group*Stimulus type	6	0.956	0.46

The results of the analysis show that only the main effects of Session ($F(2,92) = 5.428$, $p = 0.006$) and Stimulus Type ($F(1,46) = 8.676$, $p = 0.005$) are significant. With respect to the effect of Session, pairwise comparisons revealed that the RTs for Session 3 differ significantly from those for Session 1 ($p = 0.005$) and Session 2 ($p = 0.008$). As can be observed in Table 4.10, RTs are faster at Session 3.

Table 4.10 – Reaction Time (in ms) for each Session

Test	N	Mean	Range	SD
Session 1	50	813	552 - 1307	187
Session 2	50	806	513 - 1494	184
Session 3	50	757	518 - 1173	146

As for the effect of Stimulus Type, as can be seen in Table 4.11, RT for the “retroflex” trials are faster than for the “dental” trials.

Table 4.11 – Reaction Time (in ms) for each Stimulus Type

Stimulus Type	N	Mean (ms)	Range (ms)	SD
Dental	50	806	519 - 1281	164
Retroflex	50	779	560 - 1257	154

As was seen in Table 4.9, neither the main effect of Group nor any of the interactions involving this factor were significant.

Based on the hypothesis that more experienced language learners would have faster RTs, three separate One-Way ANOVAs were also performed on the RTs at Session 1, Session 2 and Session 3 with Group as factor. None of them turned out to be significant although a trend was observed at Session 3 (Session 1: $F(3,49) = 0.508, p = 0.678$; Session 2: $F(3,49) = 1.41, p = 0.252$; Session 3: $F(3,49) = 2.452, p = 0.075$). Pairwise comparisons at Session 3 reveal that early bilinguals have faster RTs than monolinguals ($p = 0.011$) and, to a certain extent, multilinguals ($p = 0.091$).

A separate repeated measures ANOVA was performed on the mean RT for each group with Session as factor. No main effect of Session was found for any of the groups (monolingual: $F(2,24) = 1.908, p = 0.17$; late bilinguals: $F(2,22) = 2.057, p = 0.152$; early bilinguals: $F(2,24) = 2.624, p = 0.093$; multilinguals: $F(2,22) = 1.448, p = 0.257$).

4.3.2 Discussion

The analysis indicates that RTs are faster at Session 3. This could be interpreted as an indication that participants are starting to feel more familiar with the task and can more easily identify the different sounds played to them. The patterns of accuracy rates described in the previous section support this interpretation since participants had higher accuracy rates for Session 3.

As for stimulus type, the analysis revealed that participants generally responded more quickly for the retroflex stimuli. A possible explanation could be that participants are quicker to recognise a sound when it is less similar to any of the sounds found in their L1 (and L2).

Language learning experience does not seem to affect RT significantly since no Group effect was found for any of the sessions and no Session effect was found for any of the groups. While a trend towards significance for the Group effect was found for Session 3, it is unclear how these results should be interpreted.

Chapter 5 – AX Discrimination Task

5.1 Method

5.1.1 Participants

A total of 66 participants were tested for this experiment. Out of these, 62 were included in the analysis (i.e. the same 50 who were included in the analysis for the training task and the 12 participants in the control group). Table 5.1 provides the number of participants in each group (for more details on which participants are in each group, see Appendix 3 – Participants Information).

Table 5.1 – Number of Participants for the AX Discrimination Task

Group	Controls	Monolinguals	Late Bilinguals	Early Bilinguals	Multilinguals
N	12	13	12	13	12

Two participants were excluded from the analysis because they provided an incorrect response for 10 or more control trials out of 48 trials (i.e. C008: control group; E037: early bilingual). Two participants were excluded because they did not participate in all three sessions (E006: late bilingual; E030: early bilingual).

5.1.2 Procedures

This component of the experiment is an AX discrimination task intended to test the discrimination abilities of the participants at the behavioural level. Again, all three contrasts were tested. Two different experiments were designed, one for the experimental contrast and another for the transfer contrast. Trials from the control contrast were included within both experiments (see section on stimuli below).

During this test, participants were presented with pairs of sounds (i.e. sound A and sound X) and asked to determine whether sounds A and X were the same sound or two different sounds. All trials were structured in the following manner: a “beep” sound to warn the participant that the trial is about to start, sound A and then sound X. A 1000 ms silence separated the “beep” and the first sound in the trial. The ISI between the two sounds within each trial was 1000 ms. A trial could end in one of two ways. If a response was recorded, the trial would end and the next trial would begin 1000ms thereafter. If no response was provided within 3 seconds, the trial would end and the next trial would begin 1000 ms thereafter (4 seconds of silence in total). Responses were provided by pressing keys on the keyboard: “z” if the two sounds were perceived as being the same or “?” key if the two sounds were perceived as being different. A piece of black felt with the labels “S” and “D”, for “same” and “different” respectively, placed on the keyboard above the keys to be pressed and covering the surrounding keys ensured that the key associated with each response was clearly identified. No feedback was provided on the answers. Moreover, the screen remained black throughout the experiment, except for when the instructions were presented. The experiment started with a short practice session to ensure that participants understood the task. The practice session consisted of six pairs of sounds selected from the set of control trials (i.e. three “same” and three “different”). Once the practice session was over, the experiment started. The experiment contained a total of 128 trials, 80 of which were experimental trials and 48 control trials. The 128 trials were divided into two blocks of 64 trials (40 experimental + 24 control trials) separated by a short break. The trials were randomised within each block for each participant. The practice trials were not included in the analysis.

The AX discrimination task was designed on Psyscope X B51 and presented on a MacBook Pro running Mac OS X version 10.5.8. Instructions were provided on the computer screen but the experimenter also explained the task verbally. Participants wore an MB Quart K 900 SC headset to listen to the stimuli. The task was performed in a sound attenuated room in the ERPLING Laboratory at the University of Ottawa.

5.1.3 Stimuli

In order to introduce some within category variation, two tokens of each phonological category were included for each contrast tested. The same subset of stimuli was used for the AX Task and the ERP experiment (see Appendix 4 – Stimuli Information).

- Experimental contrast: dental 1, dental 2, retroflex 1 and retroflex 2
- Transfer contrast: dental 1, dental 2, retroflex 1 and retroflex 2
- Control contrast: labial 1, labial 2, velar 1 and velar 2

Sixteen different types of experimental trials were created, each of which appeared five times during the experiment. Figure 5.1 below lists the various types of experimental trials included in the list of stimuli.

Thirty two different control trials were also created. These include either two sounds from the control contrast or one sound from the control contrast and one sound from the experimental/transfer contrast. The complete list of experimental and control trials along with the number of times each trial was presented can be found in Appendix 6 – List of Stimuli. Table 5.2 provides a summary of the number of trials of each type.

Figure 5.1 – Types of Experimental Trials

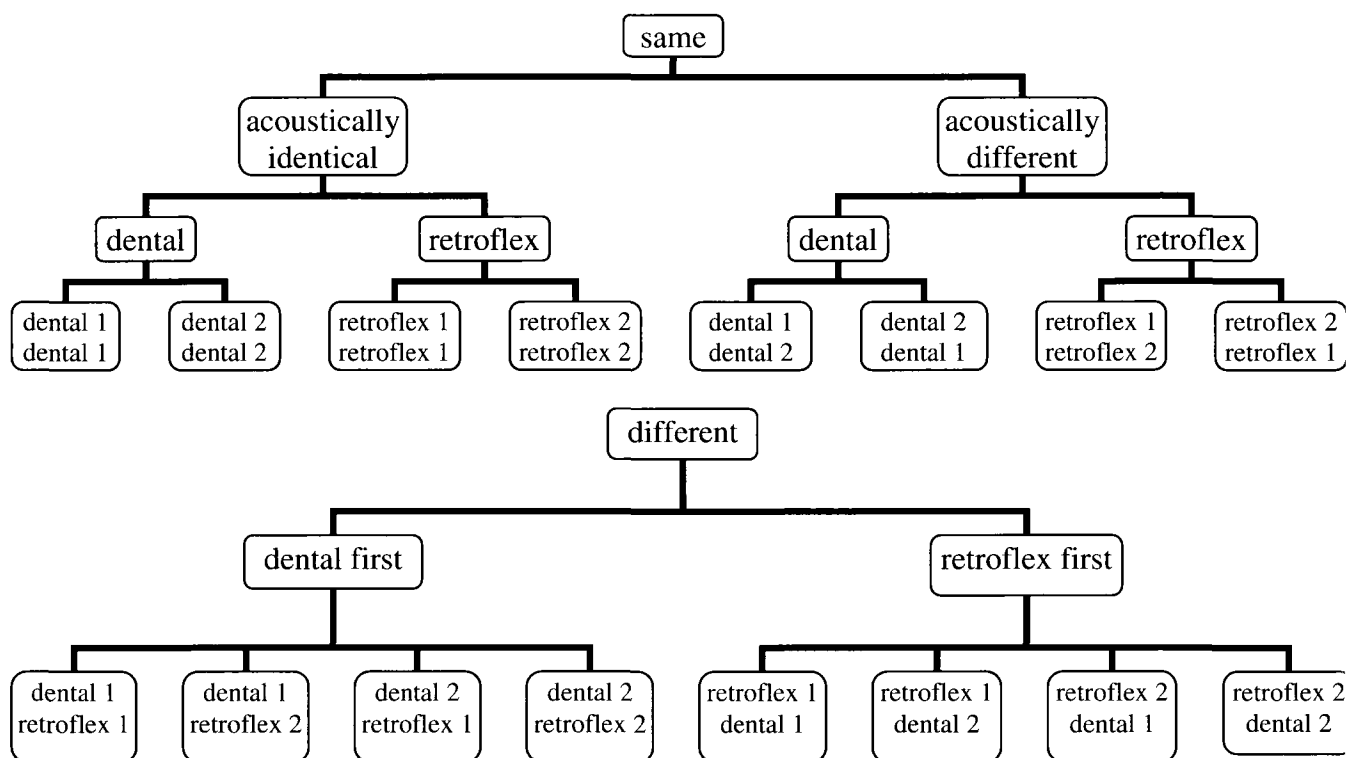


Table 5.2 – Number of trials of Each Type

	<i>same</i>	<i>different</i>	
<i>experimental</i>	8 pairs x 5 repetitions = 40	8 pairs x 5 repetitions = 40	80
<i>control</i>	8 pairs x 2 repetitions = 16	8 pairs x 2 repetitions + 16 pairs x 1 repetition = 32	48
	56	72	Total: 128

As can be seen in Table 5.2, a greater number of “different” than “same” control trials were created. This was done in order to compensate for the fact that the majority of the “different” experimental trials would be perceived as “same” by participants. Since there was an odd number of experimental trials and the trials were divided into two blocks, each block did not contain the exact same number of experimental trials of each type. As a result,

two different scripts were created for each contrast. This was done to counterbalance the number of experimental trials of each type in the two blocks. If in script 1, three trials of a given type of experimental trials appeared in block 1 and two trials of that same type appeared in block 2, then, in script 2, two trials of that type appeared in the block 1 and three appeared in block 2. Half of the participants were presented with script 1 and the other half with script 2. Participants had the same script number (i.e. 1 or 2) throughout the entire experiment, both for the behavioural and ERP components.

5.2 Accuracy Rates

5.2.1 Results

The mean accuracy rate was calculated for each participant by dividing the number of correct responses by the total number of trials for which a response was provided.¹

Accuracy rates were calculated for the experimental contrast at Pre-Test (i.e. Pre-Test) and Post-Test (i.e. Post-Test) and for the Test of Transfer at Post-Test (i.e. Transfer or Test of Transfer). A 3 (Tests) x 5 (Groups) x 2 (Stimulus Types) ANOVA was performed on the accuracy rates. The analysis revealed a main effect of Test ($F(2,114) = 24.036, p < 0.001$) and pairwise comparisons indicate that performance at Pre-Test (63%) is significantly worse than at Post-Test (74%) ($p < 0.001$) and for the Test of Transfer (67%) ($p = 0.029$).

Performance at Post-Test is also significantly better than for the Test of Transfer ($p < 0.001$). A main effect of Stimulus Type was also found ($F(1,57) = 189.649, p < 0.001$). This

¹ At Pre-Test, 10 participants did not provide a response for 1-3 trials (E004, E014, E015, E027; E028, E041, E043, E046, E050 and E051) and one participant did not provide a response for six trials (E020). At Post-Test, six participants did not provide a response for 1-4 trials (C005, E020, E029, E43, E046 and E050). For the Test of Transfer, 13 participants did not provide a response for 1-3 trials (C004, C007, E002, E004, E005, E018, E021, E027, E033, E045, E046, E050 and E053) and two participants did not provide a response for 5 trials (E029 and E043).

effect is due to the fact that, overall, participants were significantly more accurate on the “same” trials (85%) than on the “different” trials (51%). The interaction between Test and Stimulus Type also reached significance ($F(2,114) = 18.351, p < 0.001$). Test also interacted significantly with Group ($F(8,114) = 3.327, p = 0.002$). Neither the interaction between Group and Stimulus Type ($F(4,57) = 1.611, p = 0.184$) nor the three-way interaction ($F(8,114) = 1.577, p = 0.139$) were significant.

Because both interactions involving Group and Stimulus Type failed to reach statistical significance, a decision was made to rely on the sensitivity index d' (Macmillan & Creelman, 1991) instead of accuracy rates for each stimulus type separately in order to perform the statistical analysis. As opposed to the overall accuracy rates for “same” and “different” trials, this statistic takes into consideration the relationship between the “hit” rate (i.e. proportion of “different” trials correctly labelled as “different”) and the “false alarm” rate (i.e. proportion of “same” trials incorrectly labelled as “different”). The d' scores were computed for each participant for each test. A 3 (Tests) x 5 (Groups) ANOVA was performed on the d' scores in order to test for the effect of Test and Group and to determine whether there was a significant interaction between the two. The results of the analysis are presented in Table 5.3.

Table 5.3 – Test x Group ANOVA

Factor	df	F	p
Test	2	19.283	< 0.001***
Group	4	0.778	0.544
Test*Group	8	3.903	< 0.001***

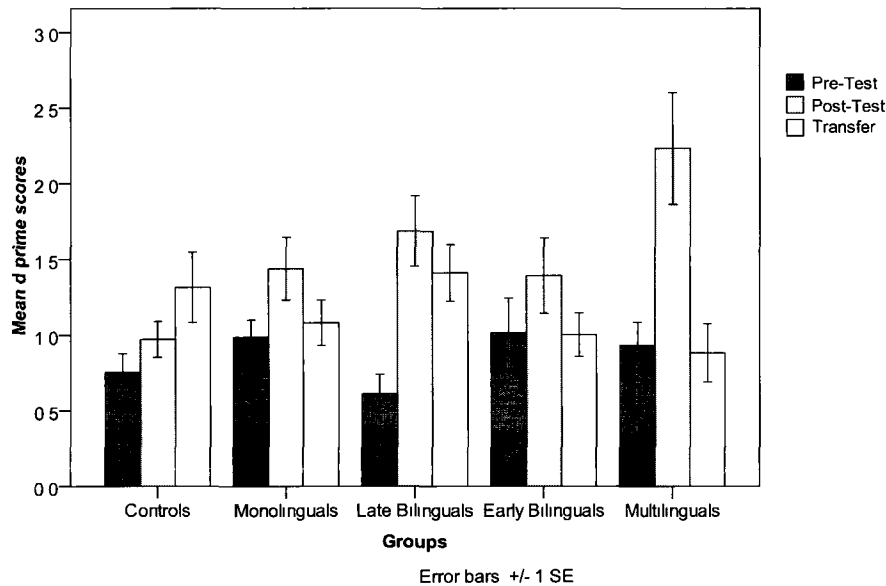
First of all, a main effect of Test was found ($F(2,114) = 19.283, p < 0.001$). Pairwise comparisons indicate that performance on all three tests differ significantly (Pre-Test vs. Post-Test: $p < 0.001$; Pre-Test vs. Transfer: $p = 0.013$; Post-Test vs. Transfer: $p < 0.001$). As can be seen in Table 5.4, participants performed significantly better at Post-Test than at Pre-Test and on the Test of Transfer. Moreover, performance on the Test of Transfer was significantly better than at Pre-Test.

Table 5.4 – Accuracy (in d' scores) for each Test

Test	N	Mean	Range	SD
Pre-Test	62	0.866	-0.363 - 3.605	0.557
Post-Test	62	1.540	0.216 - 3.681	0.936
Transfer	62	1.136	-0.597 - 3.176	0.650

The analysis also revealed that the Test x Group interaction reached significance ($F(8,114) = 3.903, p < 0.001$). As Figure 5.2 illustrates, the interaction between these two factors could be due to the fact that multilinguals and late bilinguals improve the most from Pre-Test to Post-Test.

Figure 5.2 – Test x Group Interaction



The interaction between Test and Group was further investigated by performing a repeated measures ANOVA on the d' scores with Test as factor for each group separately. The results are presented in the Table 5.5.

Table 5.5 – Repeated Measures ANOVA of Test effect for each Group

Factor	df	F	p
Controls	2	3.379	0.053
Monolinguals	2	2.55	0.10
Late Bilinguals	2	14.05	< 0.001***
Early Bilinguals	2	1.43	0.26
Multilinguals	2	11.36	< 0.001***

As can be seen in Table 5.5, the analyses revealed a significant effect of Test for late bilinguals and multilinguals and a trend toward significance for the control group but no significant effect for monolinguals and early bilinguals.

For the group of late bilinguals, pairwise comparisons indicate that performance at Pre-Test differed significantly from both Post-Test ($p = 0.001$) and the Test of Transfer ($p = 0.001$). As indicated by Table 5.6, performance improved significantly on both contrasts after training compared to Pre-Test results.

Table 5.6 – Accuracy (in d' scores) for Late Bilinguals for each Test

Test	N	Mean	Range	SD
Pre-Test	12	0.611	-0.281 - 1.115	0.444
Post-Test	12	1.686	0.481– 3.605	0.804
Transfer	12	1.411	0.000 – 2.319	0.650

As far as the multilingual group is concerned, pairwise comparisons indicated that performance at Post-Test differed significantly from performance at Pre-Test ($p = 0.001$) and for the Test of Transfer ($p = 0.005$). As illustrated in Table 5.7, performance at Post-Test was significantly better than on the other two tests.

Table 5.7 – Accuracy (in d' scores) for Multilinguals for each Test

Test	N	Mean	Range	SD
Pre-Test	12	0.936	0.309 - 1.971	0.520
Post-Test	12	2.232	0.344 - 3.681	1.273
Transfer	12	0.885	-0.597 - 1.806	0.666

Since a trend towards a significant effect of Test was observed for the control group, pairwise comparisons were also examined. The analysis revealed that the results at Pre-test differ significantly from Post-Test ($p = 0.043$) and almost significantly from the Test of

Transfer ($p = 0.053$). It can be seen from Table 5.8 that performance at Post-Test and for the Test of Transfer was better than at Pre-test. Even though performance on the Test of Transfer appears to be better than at Post-Test, the difference fails to reach significance ($p = 0.208$).

Table 5.8 – Accuracy (in d' scores) for the Control Group for each Test

Test	N	Mean	Range	SD
Pre-Test	12	0.755	-0.363 - 1.205	0.429
Post-Test	12	0.973	0.216 - 1.629	0.409
Transfer	12	1.315	0.000 - 3.176	0.805

In order to explore further the implications of the interaction between Group and Test, a 1-Way ANOVA was performed on the d' scores with Group as factor for each Test separately. The analyses revealed that the effect of Group failed to reach significance at Pre-Test ($F(4,61) = 1.198, p = 0.322$) (see Figure 5.3 and Table 5.9) and for the Test of Transfer ($F(4,61) = 1.414, p = 0.241$) (see Figure 5.5 and Table 5.11). At Post-Test, however, the effect of Group did reach significance ($F(4,61) = 3.396, p = 0.015$) (see Figure 5.4 and Table 5.10). A post-hoc analysis revealed that multilinguals performed significantly better than participants in the control group ($p = 0.001$), monolinguals ($p = 0.027$) and early bilinguals ($p = 0.019$). A significant difference was also observed between late bilinguals and the control group ($p = 0.05$).

Figure 5.3 – Accuracy (in d' scores) for each Group at Pre-Test

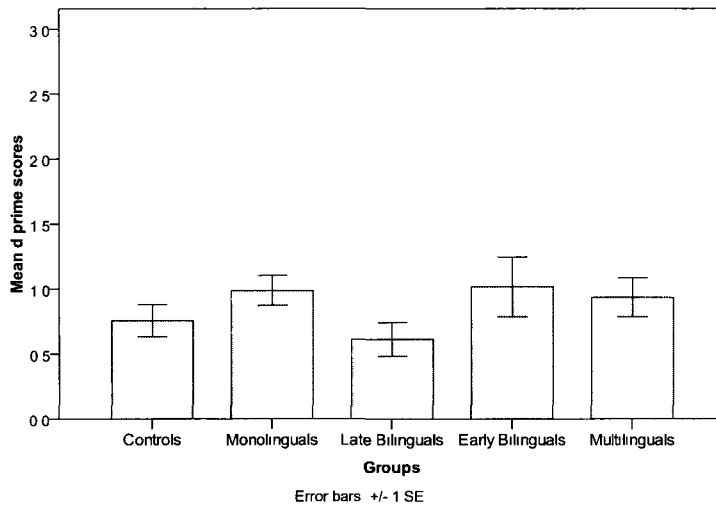


Table 5.9 – Accuracy (in d' scores) for each Group at Pre-Test

Group	N	Mean	Range	SD
Controls	12	0.755	-0.363 - 1.205	0.429
Monolinguals	13	0.988	0.302 - 1.879	0.411
Late Bilinguals	12	0.612	-0.281 - 1.115	0.444
Early Bilinguals	13	1.016	0.287 - 3.605	0.829
Multilinguals	12	0.936	0.309 - 1.971	0.520

Figure 5.4 – Accuracy (in d' scores) for each Group at Post-Test

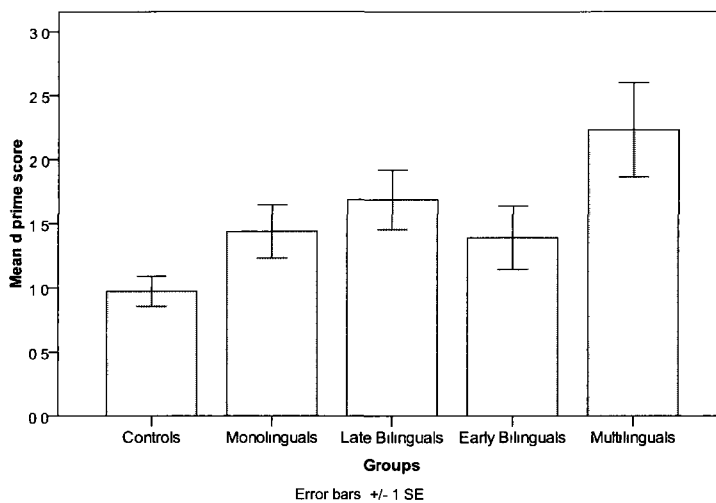


Table 5.10 – Accuracy (in d' scores) for each Group at Post-Test

Group	N	Mean	Range	SD
Controls	12	0.973	0.216 - 1.629	0.409
Monolinguals	13	1.439	0.574 - 2.802	0.749
Late Bilinguals	12	1.686	0.481 - 3.601	0.804
Early Bilinguals	13	1.392	0.410 - 3.278	0.894
Multilinguals	12	2.232	0.344 - 3.681	1.273

Figure 5.5 – Accuracy (in d' scores) for each Group for the Test of Transfer

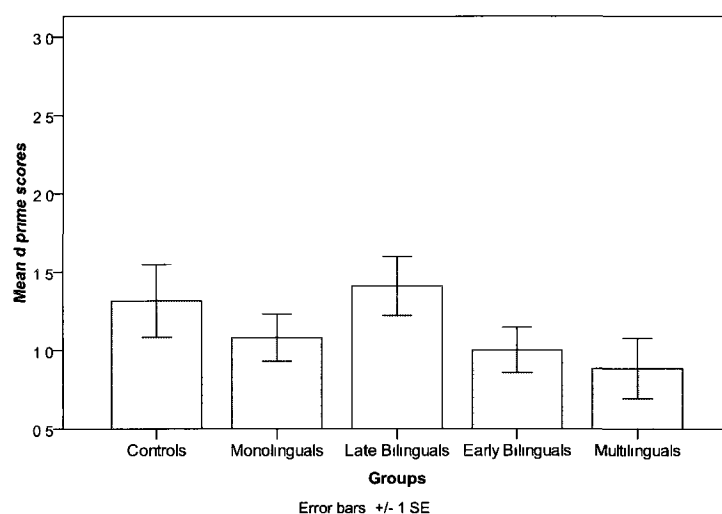


Table 5.11 – Accuracy (in d' scores) for each Group for the Test of Transfer

Group	N	Mean	Range	SD
Controls	12	1.315	0.000 - 3.176	0.805
Monolinguals	13	1.082	0.000 - 1.906	0.541
Late Bilinguals	12	1.411	0.000 - 2.319	0.650
Early Bilinguals	13	1.002	0.102 - 2.037	0.519
Multilinguals	12	0.885	-0.597 - 1.806	0.666

5.2.2 Discussion

The initial analysis performed on the accuracy rates with Stimulus Type (i.e. “same” and “different” trials) as a factor revealed that, overall, “same” trials were more easily identified than “different” trials. This is not surprising since this experiment tests two contrasts that are not found in the languages known by the participants. Since Stimulus Type did not interact with group membership and since, as was explained earlier, d' scores were judged to be better suited for this type of analysis, the rest of the analysis was performed on the d' scores.

The analysis revealed a main effect of Test which can be interpreted as indicating that, in general, performance differed on the three tests. As indicated by the planned comparisons, participants performed better at Post-Test than at Pre-Test. This suggests that, overall, training improved discrimination abilities on the voiceless aspirated dental vs. retroflex stop contrast. When looking at how the different language groups compare at Pre-Test and Post-Test, it is clear that training did not have the same effect on all groups. Two separate analyses suggest that multilinguals and late bilinguals benefited the most from training. First of all, the performance of multilinguals and late bilinguals improved significantly from Pre-Test to Post-Test while that of monolinguals and early bilinguals did not. Moreover, multilinguals and late bilinguals performed significantly better than the control group at Post-Test which, once again, is not the case for their monolingual and early bilingual counterparts. Finally, it is important to note that multilinguals stand out as the most improved group since their performance after training is also significantly better than that of monolinguals and early bilinguals. The results of the AX task therefore suggest that,

at the behavioural level, although language learning experience may not affect initial discrimination abilities before training, it does affect learning rates. The difference between two vs. three languages and late versus early L2 acquisition will be discussed in Chapter 7 – General Discussion and Conclusions.

Overall, participants were also more accurate on the transfer contrast than on the experimental contrast at Pre-Test. First of all, it could be that the voiceless unaspirated contrast is simply easier to discriminate than the voiceless aspirated one. Nevertheless, this hypothesis can safely be rejected since native speakers of American English, who were tested with the same stimuli by Pruitt et al. (2006), were not significantly better at discriminating the voiceless unaspirated contrast than the voiceless unaspirated one before training and, in fact, performed slightly better on the voiceless aspirated one than the unaspirated one. There are reasons to believe that the better performance on the transfer contrast compared to the performance on the experimental contrast at Pre-Test is not due to transfer of training either, but rather to the fact that participants simply had more experience with the task by the time they performed the Test of Transfer. This interpretation is supported when the interaction between Test and Group is examined more closely. First of all, no Group effect was found for the Test of Transfer, suggesting that the experimental groups did not necessarily differ from the control group. Moreover, the response pattern of the control group, which is slightly different from that observed for the other groups, reinforces the hypothesis of the exposure effect. As could be seen in Table 5.8 above, the performance by the control group improves from test session to test session such that performance is best for the Test of Transfer (although the difference only reaches

significance between Pre-Test and Post-Test). For the experimental groups, although the difference is only significant for multilinguals and late bilinguals, performance is generally best at Post-Test. It is therefore difficult to determine whether there is in fact transfer of training or whether the results are simply due to exposure. Nevertheless, when the difference between Pre-Test and the Test of Transfer is considered for each group separately, the difference turns out to be significant for the group of late bilinguals. This raises the question as to whether transfer of training is only apparent for this group. At this point, it is impossible to make any claims regarding the effect of language learning experience on transfer of training at the behavioural level. It would nevertheless be interesting to see whether a clearer trend would be observed with more extensive training.

5.3 Reaction Times

5.3.1 Results

The mean RT was calculated for each participant for each stimulus type at each test (i.e. Pre-Test, Post-Test and Test of Transfer). Mean RT was based on both correct and incorrect responses. A 3 (Tests) x 5 (Groups) x 2 (Stimulus Types) ANOVA was performed on the mean RTs to investigate the effect of Test, Group and Stimulus Type and to determine whether there is a significant interaction between any of these factors. The results are presented in Table 5.12 below.

As can be seen in Table 5.12, the results of the analysis revealed a main effect of Test ($F(2,114) = 7.159, p = 0.001$). Pairwise comparisons showed that RTs were significantly

shorter for the Test of Transfer than for the Pre-Test ($p = 0.016$) and Post-Test ($p < 0.001$) (Table 5.13).

Table 5.12 – Session x Group x Stimulus Type ANOVA

Factor	df	F	p
Test	2	7.159	0.001**
Group	4	0.926	0.455
Stimulus Type	1	82.692	< 0.001***
Test*Group	8	1.29	0.256
Test*Stimulus type	2	3.367	0.038*
Group*Stimulus type	4	0.699	0.596
Test*Group*Stimulus type	8	1.211	0.299

Table 5.13 – Reaction Time (in ms) for each Test

Test	N	Mean	Range	SD
Pre-Test	62	2427	1979 - 3393	272
Post-Test	62	2444	1937 - 2968	242
Transfer	62	2364	1893 - 2840	232

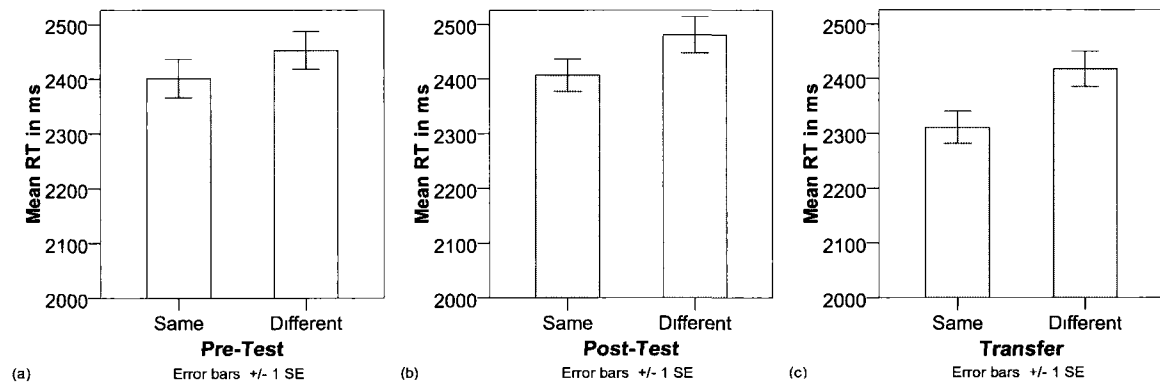
As seen in Table 5.12, a main effect of Stimulus Type was also found ($F(1,57) = 82.692$, $p < 0.001$). As can be seen in Table 5.14, the difference is due to the fact that RTs for “different” trials are significantly longer than for “same” trials.

Table 5.14 – Reaction Time (in ms) for each Stimulus Type

Stimulus Type	N	Mean	Range	SD
Same	62	2373	1926 - 2898	223
Different	62	2450	1966 - 2996	237

A significant interaction was found between Test and Stimulus Type ($F(2,114) = 3.367, p = 0.038$). As shown in Figure 5.6, this interaction appears to be due to the fact that RTs are faster for “same” trials than for “different” trials and that this is especially the case for the Test of Transfer.

Figure 5.6 – Reaction Time (in ms) for Same and Different Trials for each Test



As shown in Table 5.12 above, neither the main effect of Group nor any of the interactions involving this factor (i.e. Test x Group, Group x Stimulus Type and Test x Group x Stimulus Type) were significant. For this reason, the interaction between Group and Test was not investigated any further.

5.3.2 Discussion

The analysis revealed that RTs are faster for the Test of Transfer than for the other two tests. This could be interpreted in various ways. First of all, it could be due to the fact that participants had more difficulty with this contrast than with the experimental contrast at Pre-Test and Post-Test and therefore provided an answer quickly because they simply

could not hear any difference between the sounds. However, while it is the case that participants performed better at Post-Test, they were actually more accurate on the transfer contrast than on the experimental contrast at Pre-Test. Alternatively, the faster RTs for the Test of Transfer could be related to the fact that this task was the very last component of the experiment. This could have influenced the RTs in two ways. First of all, participants were more familiar with the task since it was the third time they performed the AX task. Moreover, participants performed this task at the end of Session 3 after being in the laboratory for about two hours in most cases. It is therefore possible that participants were a little tired by the time they performed the task and did so more quickly. Lastly, the faster reaction times could simply be related to the fact that the stimuli are slightly shorter in duration for the transfer contrast than for the experimental contrast (see Appendix 4).

A main effect of Stimulus Type was also found, which indicated that participants are slower to provide a response for “different” trials compared to “same” trials. This suggests that “same” trials were generally more easily identified and that participants hesitated more to provide their response when they thought they might have heard a difference between the two sounds. The interaction between Stimulus Type and Test also reached significance levels. As mentioned above, this could be due to the fact that while responses were generally faster for the “same” trials, it was especially true for the Test of Transfer.

The fact that neither the main effect of Group nor any of the interactions involving this factor turned out to be statistically significant is interpreted as an indication that language learning experience does not have an impact on RTs on this type of task.

Chapter 6 – Event-Related Potential Experiment

6.1 Method

6.1.1 Participants

A total of 65 participants were tested. Out of these, 60 were included in the analysis. Table 6.1 provides the number of participants in each group (for more details on which participants are in each group, see Appendix 3 – Participants Information).

Table 6.1 – Number of Participants for the ERP Experiment

Group	Controls	Monolinguals	Late Bilinguals	Early Bilinguals	Multilinguals
N	13	12	12	12	11

Five participants were excluded from the analysis because they did not have a complete set of ERP data. Two participants were only asked to perform the behavioural tasks and were not asked to perform the ERP task at Session 3 because of noisy ERP data at Session 1 (i.e. E002: early bilingual; E004: monolingual). Three participants were excluded because they did not participate in all three sessions (E006: late bilingual; E014: multilingual; E030: early bilingual). It should also be noted that participant E026, who participated in the behavioural experiment, did not take part in the ERP experiment because of his left-handedness.

6.1.2 Procedures

This component of the experiment was intended to observe the neurophysiological responses to the acoustic change when a new sound (deviant) is randomly presented among

a string of reoccurring sounds (standard). The three contrasts (i.e. control¹, experimental and transfer contrast) were tested separately using the same method. In other words, three experiments were designed, each containing sounds from only one contrast. The stimuli were presented using an oddball paradigm. The experiment was designed so that the deviant amounted to at most 15% of the total 750 stimuli (average: approximately 11%). Each experiment started with a minimum of 10 standards and each deviant was separated by a minimum of three standards. The ISI ranged randomly from 650 ms to 750 ms within each experiment. Each experiment lasted between about 12 and 16 minutes.²

For this part of the experiment, participants wore a cap with electrodes (64 channel Compumedics Quick Cap, Model C190) connected to a SynAmps 2 amplifier hooked up to a Pentium® 4 CPU 3.40 GHz with 1GB of RAM running Microsoft Windows XP version 2002 which recorded the neurophysiological activity using Scan 4.3. As a rule, impedances were 5 kOhms or lower. A Pentium® D CPU 3.40 GHz with 1GB of RAM running Microsoft Windows XP version 2002 using Presentation® software (Version 12.2, www.neurobs.com) was used to present the stimuli. The stimuli were presented through STIM 10 Ohm insert earphone and the volume was adjusted on an individual basis before the start of the experiment. Participants were asked to identify a level at which they could hear very well but were not irritated by the loudness of the sounds. During the presentation of the stimuli, participants sat comfortably about 1.5 meters (3 feet) from a 15 inch screen on which a silent movie was presented. Participants could choose between three different DVDs from the Planet Earth documentary series (Fothergill, 2007). Before the experiment

¹ This contrast is not considered in the present analysis.

² The duration of the experiment was slightly different from one experiment to the next because of stimuli duration and the random selection of the ISI by the program.

started, participants were instructed not to pay attention to the stimuli (Näätänen, 2001; Tiitinen et al., 1994) and to try to keep their blinking and movements to a minimum and to sit still in a relaxed position.

6.1.3 Stimuli

In order to introduce some within category variation, two tokens of each phonological category were included for each contrast tested. The same subset of stimuli used for the AX task was used for this part of the experiment (see Appendix 4 – Stimuli Information).

- Experimental contrast: dental 1, dental 2, retroflex 1 and retroflex 2
- Transfer contrast: dental 1, dental 2, retroflex 1 and retroflex 2
- Control contrast: labial 1, labial 2, velar 1 and velar 2

The scripts were programmed such that both tokens within the same category were presented roughly 50% of the time. Two different versions of each experiment were created for each contrast in which the standard and the deviant were inverted. Half of the participants were presented with script 1 (standard: dental/labial; deviant: retroflex/velar) and the other half with script 2 (standard: retroflex/velar; deviant: dental/labial). Participants had the same script number (i.e. 1 or 2) throughout the entire experiment, both for the behavioural and the ERP components.

6.1.4 Analysis

6.1.4.1 Artefact Correction and Rejection

The adaptive artefact correction model by Ille, Berg & Sherg (2002) was used for off-line artefact correction and rejection with BESA (Version 5.2.4.48, MEGIS Software, Munich,

Germany). The recordings were scanned a first time for artefacts using a default setting (120 μ V maximum amplitude, 0.01 μ V minimum signal, 75 gradient). Visual inspection allowed for the exclusion of all trials that appeared over 120 μ V. Artefacts that were not rejected were then corrected using the adaptive artefact correction model producing a complementary VEOG and HEOG continuous waveform. These waves were applied to the recorded VEOG and HEOG channels to counteract any artefacts generated by blinks, horizontal eye movements, signal clipping by the amplifier and other movement artefacts. The corrected waveforms were then scanned a second time using the criteria used for the first scan in order to identify and reject any remaining artefacts that could not be corrected.

Averaging of the recordings was based on 700 ms epochs from 100 ms pre-stimulus onset until 600 ms post-stimulus onset. All averages were filtered with a 60-Hz low pass digital filter. Averages for each participant include all deviant trials and the standard trials preceding each of them. As a result, a similar number of deviant and standard trials was included in the averages. The average percentage of trials that were corrected and rejected for each group and each contrast can be found in Appendix 7 – Artefact Correction and Rejection.

6.1.4.2 Analysis

Average waves for the standard and the deviant conditions were exported for six different time windows from 100 ms to 400 ms post stimulus onset using BESA: 100-150 ms, 150-200 ms, 200-250 ms, 250-300 ms, 300-350 ms and 350-400 ms. Difference waves were computed for each time window by subtracting the average for the standard condition from the average for the deviant condition. Moreover, in order to look more closely at learning

rates (i.e. Pre-Test vs. Post-Test differences), a difference wave was computed for each time window by subtracting the difference wave at Pre-Test from the difference wave at Post-Test.

Based on previous findings in the ERP oddball literature and on visual inspection of the present data, a subset of electrodes was selected for the analysis: F3, Fz, F4, FC3, FCz, FC4, C3, Cz and C4. These electrodes were analysed for three levels of anteriority and three levels of laterality. Throughout this chapter, anteriority refers to frontal (F), fronto-central (FC) and central (C) and laterality refers to left, midline and right. Only significant results and trends with a p value of 0.1 or lower are reported.

Statistical analyses were also performed on averages for combinations of electrodes. First of all, an average for each laterality was computed in order to investigate group differences between the left (i.e. F3, FC3 and F3 combined), midline (i.e. Fz, FCz and Cz combined) and right (i.e. F4, FC4 and C4 combined) regions. Furthermore, an average for each anteriority was computed in order to investigate group differences between the frontal (i.e. F3, Fz and F4 combined), fronto-central (i.e. FC3, FCz and FC4 combined) and central (i.e. C3, Cz and C4 combined) regions. Whenever a significant interaction was found between either Laterality or Anteriority and Group, a 1-way ANOVA was performed on each laterality or anteriority in order to look for any significant effect of Group.

6.2 Results

6.2.1 Outline of Results Section

In this section, the results of the analysis of the ERP experiment will be presented. First, the results at Pre-Test and at Post-Test will be presented individually and then the effect of training, namely the Pre-Test – Post-Test differences, will be presented. Lastly, the results for the Test of Transfer will be presented. The same terminology used for the AX task will be used to refer to the various tests (i.e. experimental contrast at pre-test: Pre-Test; experimental contrast at post-test: Post-Test; transfer contrast at post-test: Transfer or Test of Transfer). The group average waves will be provided in a series of figures at the beginning of the respective sections. In all of these figures, the red line presents the average wave for the deviant and the black line represents the average wave for the standard. While only the electrode sites that were analysed are presented in this chapter, figures containing all of the electrode sites recorded can be found in Appendix 8 – Electroencephalographic Recordings.

6.2.2 Pre-Test

6.2.2.1 Observations

As can be seen in Figures 6.1 through 6.5, an MMN can be observed for the control group, monolinguals and multilinguals for the non-native contrast at Pre-Test. As for early bilinguals, it is not clear whether they show a small MMN or no MMN at all. Late bilinguals do not seem to exhibit an MMN. Among the groups that do show an MMN, some differences can be observed. First of all, the amplitude of the MMN appears to be larger for multilinguals compared to the other groups. Moreover, while all of the groups that do show an MMN seem to show the effect in the midline and the right side electrodes,

multilinguals are the only group who show a clear MMN on the left side electrodes as well. As can be seen in Figure 6.6, the difference on the left side is especially visible in F3 and FC3. Various statistical analyses were performed in order to determine whether any of the differences that are apparent upon visual inspection of the average waves can be confirmed statistically.

Figure 6.1 – Control Group at Pre-Test

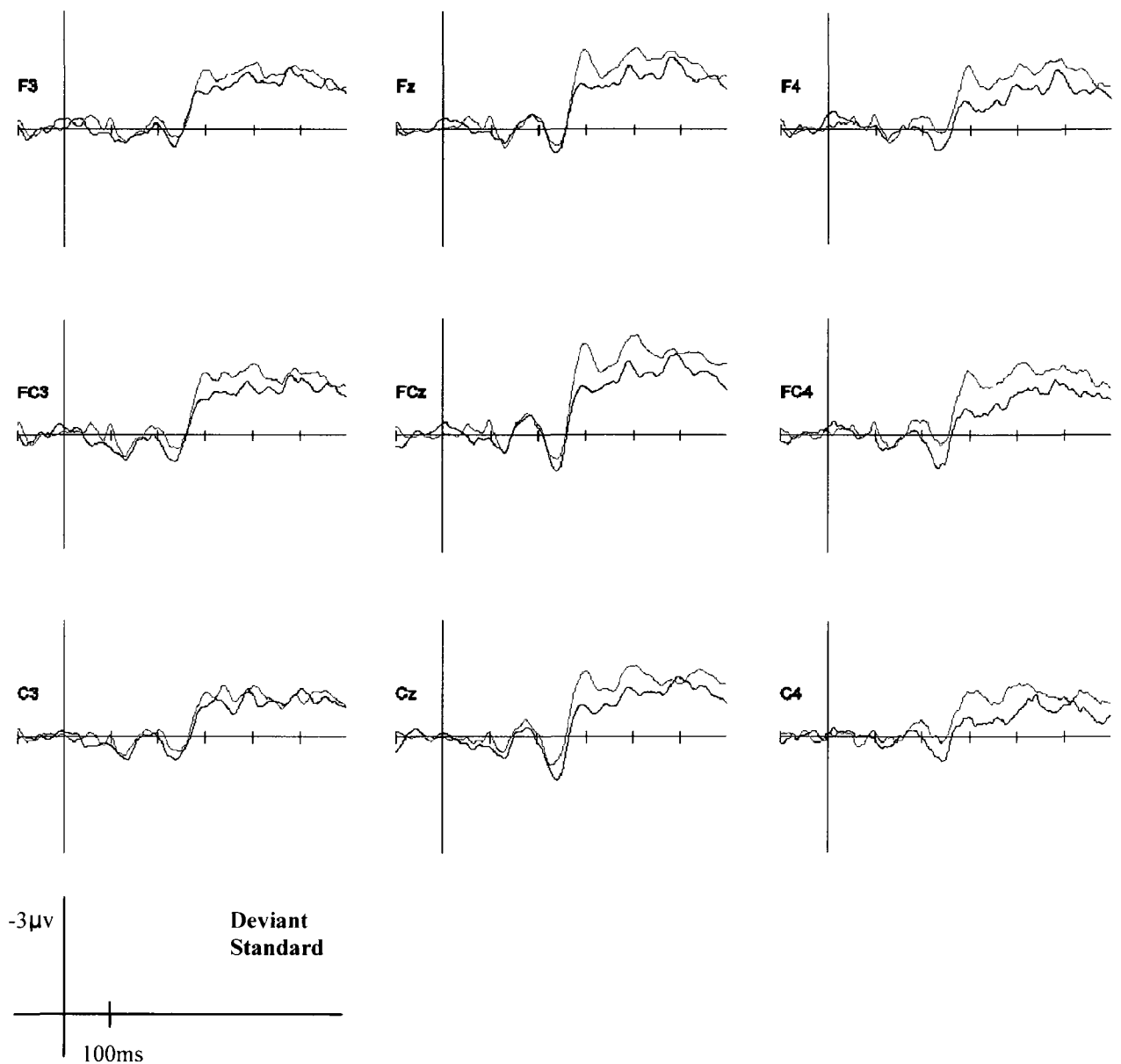


Figure 6.2 – Monolinguals at Pre-Test

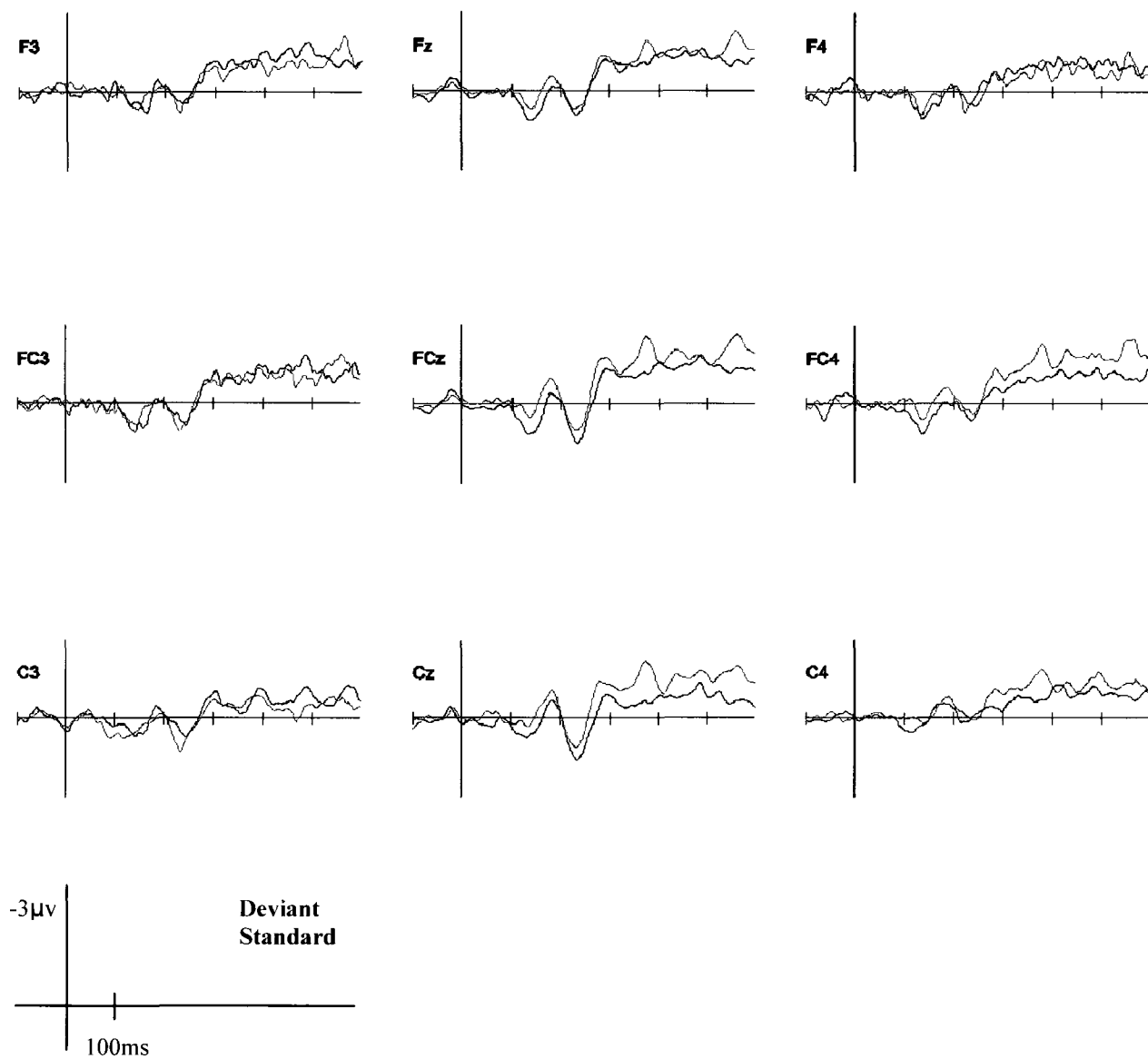


Figure 6.3 – Late Bilinguals at Pre-Test

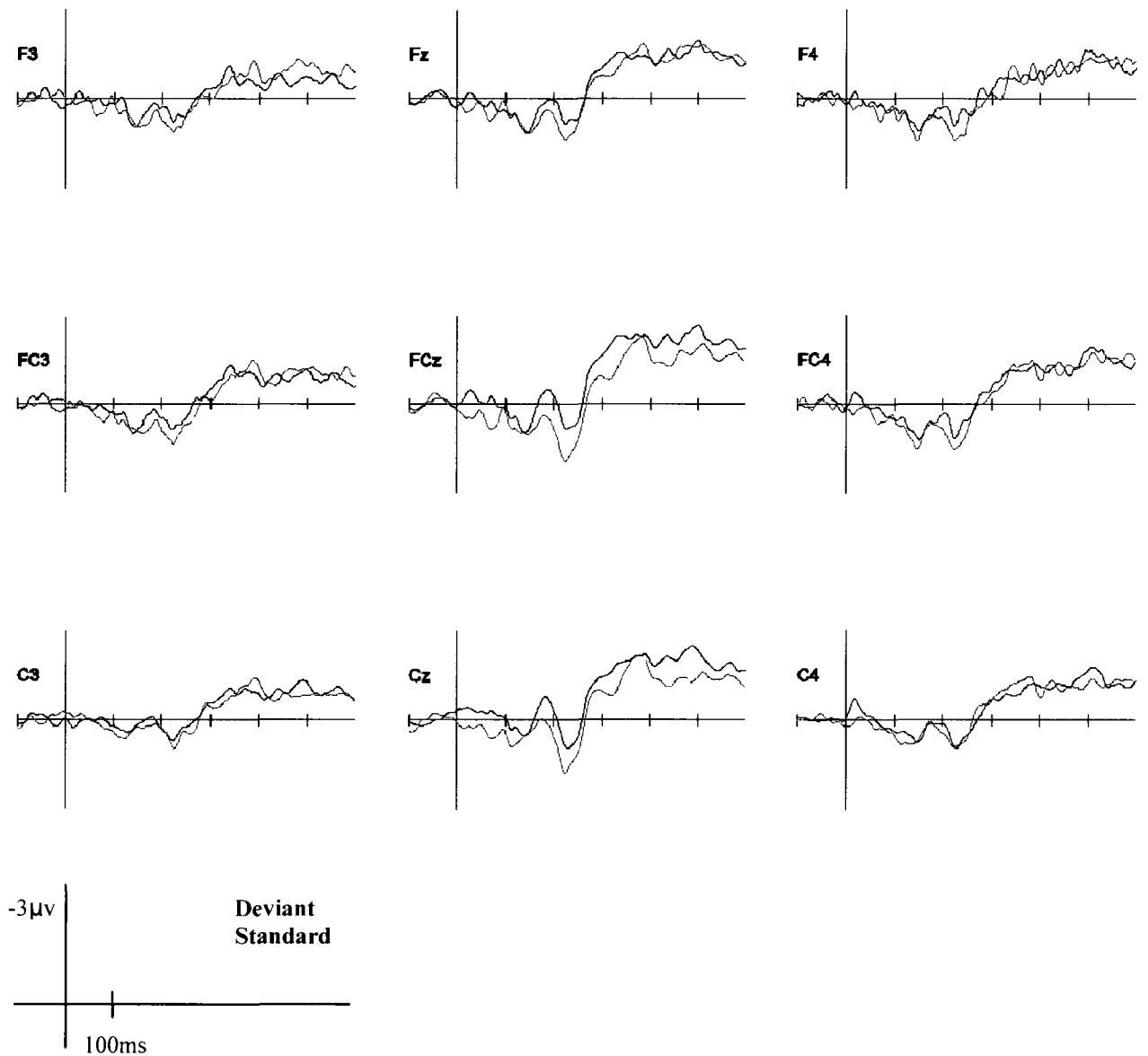


Figure 6.4 – Early Bilinguals at Pre-Test

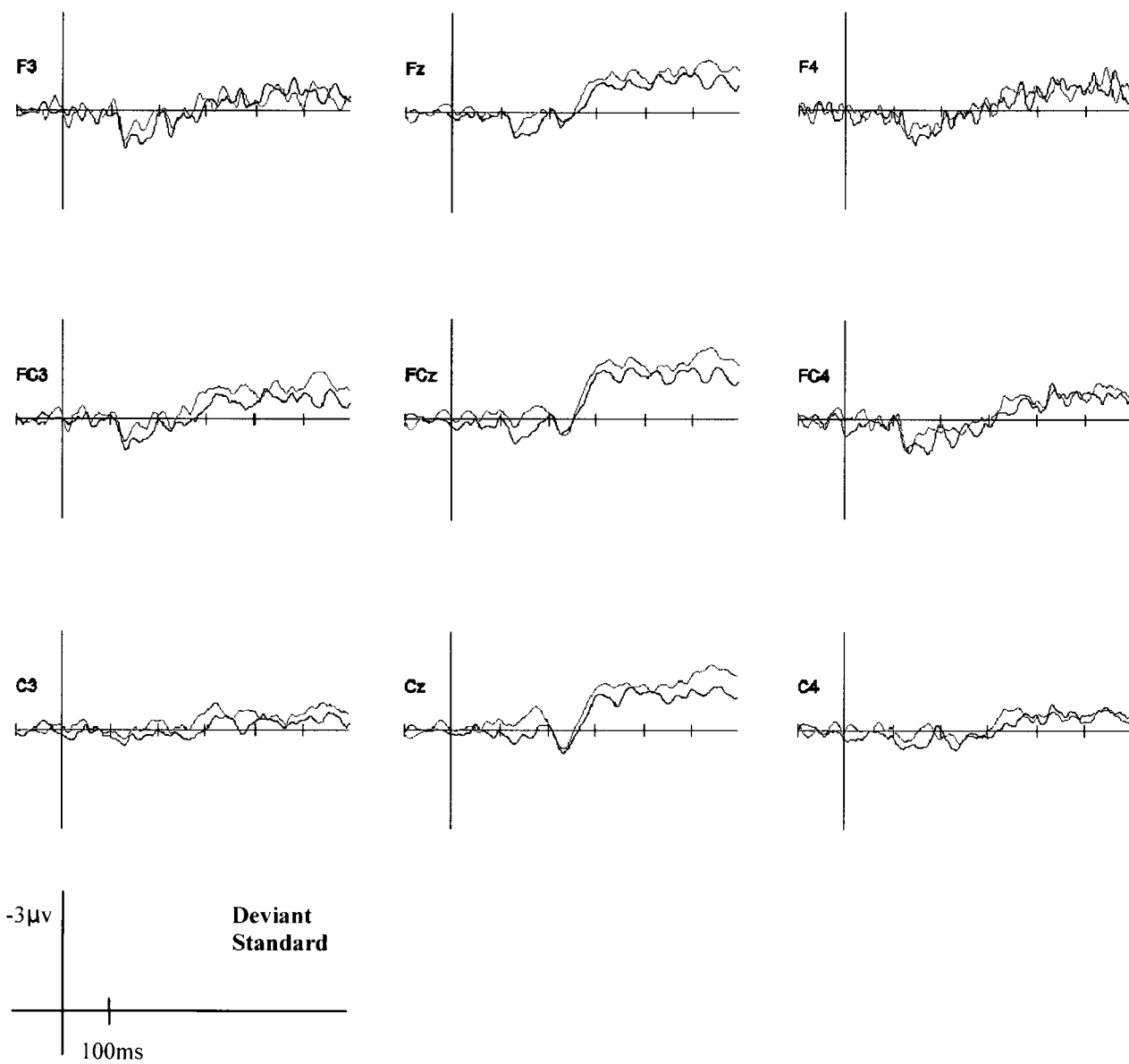


Figure 6.5 – Multilinguals at Pre-Test

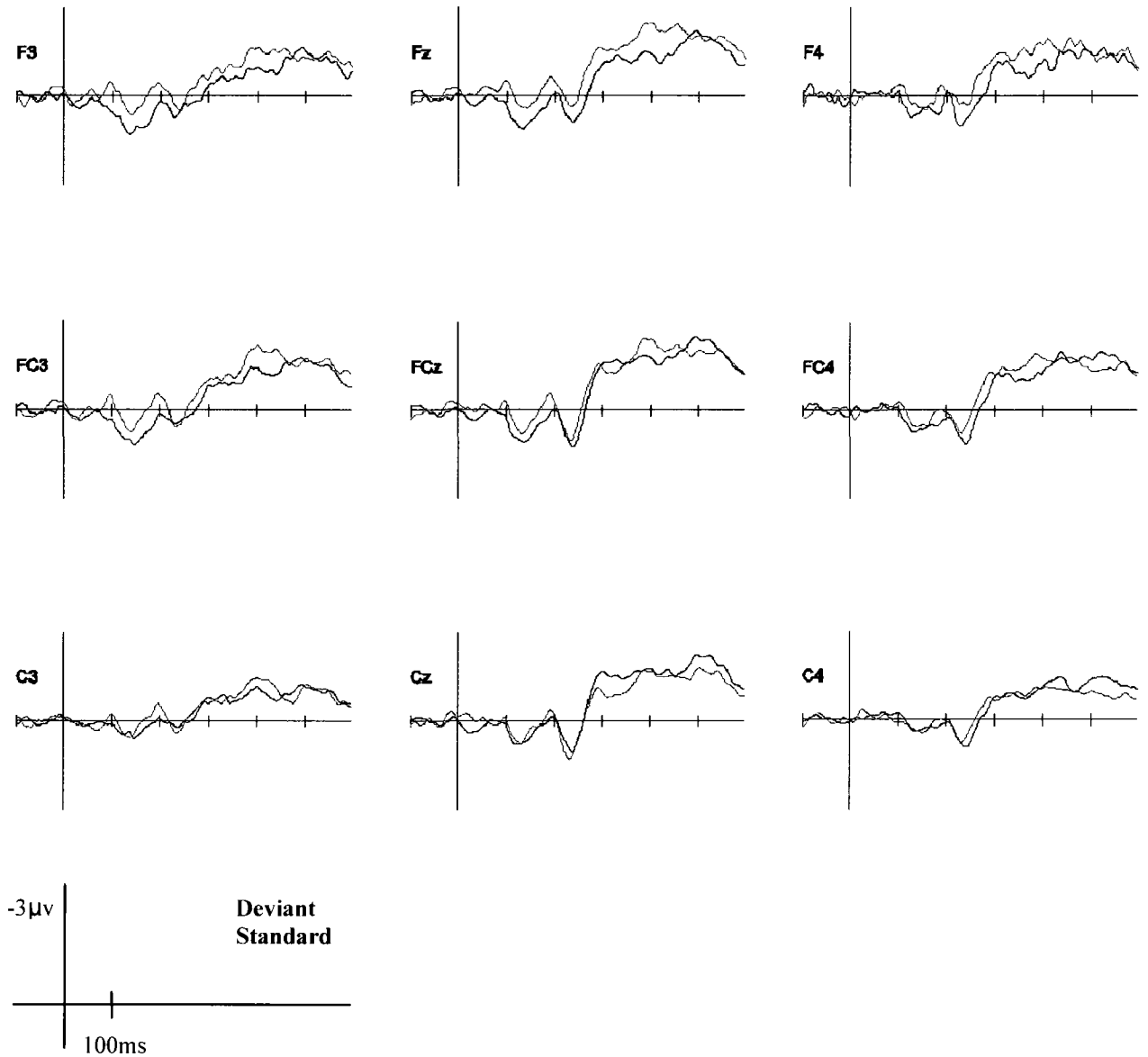
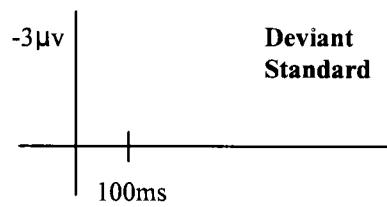
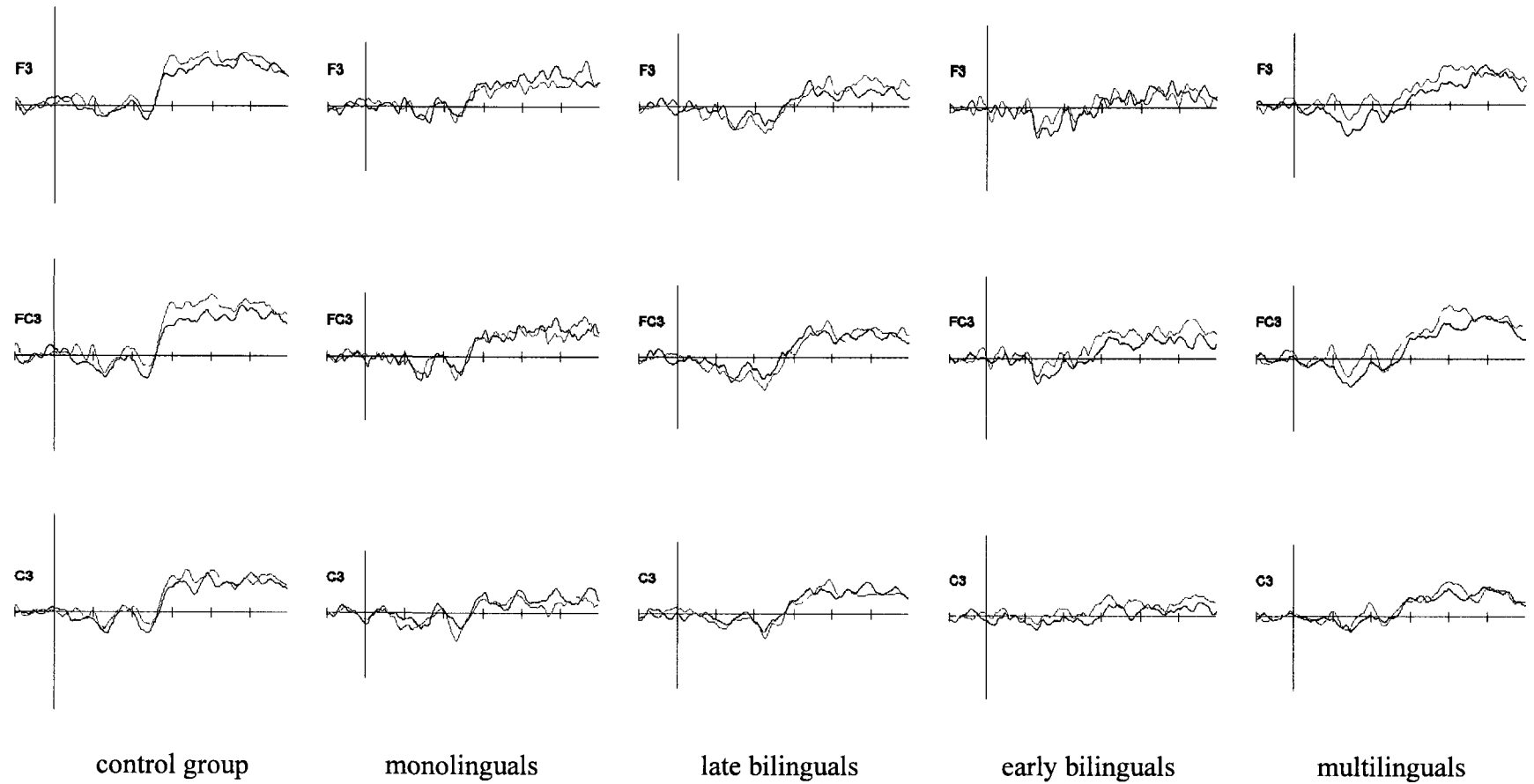


Figure 6.6 – Left Electrodes for all Groups at Pre-Test



6.2.2.2 Statistical Analysis

An initial ANOVA was performed on the difference waves at Pre-Test with Anteriority and Laterality as within subject-factors and Group as between-subject factor. The results are presented in Table 6.2. Only significant and trends towards significant effects are reported.

Table 6.2 – Anteriority x Laterality x Group ANOVA

Time window	Factor	df	F	p
150-200 ms	Group	4	2.932	0.029*
200-250 ms	Group	4	2.276	0.073
250-300 ms	Anteriority*Group	8	2.250	0.029*
	Anteriority*Laterality*Group	16	1.764	0.037*
300-350 ms	Group	4	2.254	0.075
	Anteriority*Group	8	2.266	0.028*
350-400 ms	Anteriority*Group	8	2.437	0.018*

As can be seen in Table 6.2, the analysis revealed a significant or near significant effect of Group for three of the time windows (150-200 ms, 200-250 ms and; 300-350 ms). At 150-200 ms, pairwise comparisons indicated that the effect of Group was due to the fact that the amplitude of the difference wave for late bilinguals was significantly smaller than for monolinguals ($p = 0.035$), early bilinguals ($p = 0.005$), multilinguals ($p = 0.005$) and, although the difference did not reach significance levels, the control group ($p = 0.081$). At 200-250 ms, pairwise comparisons indicate that the trend towards significance for the Group effect was due to a significantly smaller amplitude of the difference wave for late bilinguals compared to multilinguals ($p = 0.031$), the control group ($p = 0.006$) and, to some extent, early bilinguals ($p = 0.059$). At 300-350 ms, pairwise comparisons indicated that the trend towards significance for the Group effect was due to a significantly smaller difference wave amplitude for late bilinguals compared to the control group ($p = 0.005$).

Moreover, although the difference is not significant, the amplitude of the difference wave for monolinguals and multilinguals was also smaller than for the control group ($p = 0.09$ and $p = 0.081$ respectively). Finally, the difference wave for late bilinguals was also almost significantly smaller than that for early bilinguals ($p = 0.084$).

In order to look further into the interaction between Group and Anteriority reported in Table 6.2 at three different time windows (250-300 ms, 300-350 ms and 350-400 ms), a 1-way ANOVA was performed for each anteriority separately (i.e. Frontal: F; Fronto-Central: FC; Central: C) in order to look for a Group effect. The significant effects and trends are reported in Table 6.3.

Table 6.3 – 1-way ANOVA for Group Effect on each Anteriority

Anteriority	Time window	df	F	<i>p</i>
FC	150-200 ms	4	3.263	0.018*
	200-250 ms	4	2.452	0.057
	250-300 ms	4	2.070	0.097
	300-350 ms	4	2.648	0.043*
C	300-350 ms	4	2.836	0.033*

As can be seen in Table 6.3, a significant effect of Group or a trend towards significance for an effect of Group was found for four different time windows in the fronto-central electrodes (150-200 ms, 200-250 ms, 250-300 ms and 300-350 ms). At 150-200 ms, pairwise comparisons show that the effect was due to the fact that the amplitude of the difference wave was significantly smaller for late bilinguals compared to monolinguals ($p = 0.01$), early bilinguals ($p = 0.004$), multilinguals ($p = 0.004$) and, to some extent, the control group ($p = 0.06$). At 200-250 ms and 250-300 ms, the trend towards significance for

the Group effect was also due to the fact that the amplitude of the difference wave was smaller for late bilinguals than for all of the other groups (200-250 ms: monolinguals: $p = 0.055$; early bilinguals: $p = 0.049$; multilinguals: $p = 0.029$; control group: $p = 0.004$; 250-300 ms: monolinguals: $p = 0.076$; early bilinguals: $p = 0.059$; multilinguals: $p = 0.037$; control group: $p = 0.009$). Lastly, with respect to the 300-350 ms window, the effect of Group was due to the fact that the amplitude of the difference wave for late bilinguals is smaller than for early bilinguals ($p = 0.053$) and the control group ($p = 0.002$). Moreover, the amplitude of the difference wave for multilinguals was smaller than for the control group ($p = 0.071$).

Turning to the Group effect for the central electrodes at 300-350 ms ($F(4,59) = 2.836$, $p = 0.033$), pairwise comparisons reveal that the effect of Group was due to the fact that the amplitude of the difference wave for late bilinguals was smaller than for early bilinguals ($p = 0.077$) and the control group ($p = 0.01$). Moreover, the amplitude of the difference wave for multilinguals was smaller than for the control group ($p = 0.008$) and early bilinguals ($p = 0.064$).

Based on the research hypotheses and the fact that a significant three-way interaction was found, a 1-way ANOVA was also performed on each laterality in order to look for any group differences. The results are presented in Table 6.4.

Table 6.4 – Effect of Group for Left, Midline and Right Electrodes

Laterality	Time window	df	F	<i>p</i>
Left	150-200 ms	4	2.797	0.035*
Midline	150-200 ms	4	2.585	0.047*
	200-250 ms	4	2.092	0.094
	250-300 ms	4	2.055	0.099
	300-350 ms	4	2.584	0.047*
Right	200-250 ms	4	2.140	0.088

With respect to the left laterality, a significant Group effect was found for the 150-200 ms window ($F(4,59) = 2.797, p = 0.035$). Pairwise comparisons confirm that the amplitude of the difference wave for multilinguals was significantly greater than that of late bilinguals ($p = 0.003$) and approached significance compared to monolinguals ($p = 0.053$) and the control group ($p = 0.091$). Moreover, the difference wave measured for early bilinguals had a significantly greater amplitude than the one for late bilinguals ($p = 0.023$).

As for the midline electrodes, the statistical analysis confirmed that Group was a significant factor over several time windows (150-200 ms: $F(4,59) = 2.585, p = 0.047$; 200-250 ms: $F(4,59) = 2.092, p = 0.094$; 250-300 ms: $F(4,59) = 2.055, p = 0.099$; 300-350 ms: $F(4,59) = 2.584, p = 0.047$). For the 150-200 ms window, the amplitude of the difference wave for late bilinguals was significantly smaller than the one for monolinguals ($p = 0.018$), early bilinguals ($p = 0.007$) and multilinguals ($p = 0.017$). For the 200-250 ms window, the amplitude of the difference wave for late bilinguals was significantly smaller than the one for monolinguals ($p = 0.021$), multilinguals ($p = 0.031$) and the control group ($p = 0.017$) and, to some extent, early bilinguals ($p = 0.064$). At 250-300 ms, the amplitude of the difference wave for late bilinguals was significantly smaller than the one for monolinguals

($p = 0.039$) and the control group ($p = 0.009$). Moreover, although the difference was not significant, it was also smaller than for early bilinguals ($p = 0.075$) and multilinguals ($p = 0.076$). At 300-350 ms, the amplitude of the difference wave for late bilinguals was significantly smaller than the one for early bilinguals ($p = 0.037$) and the control group ($p = 0.004$) and, to some extent, monolinguals ($p = 0.075$). Finally, the amplitude of the difference wave for multilinguals was close to being significantly smaller than for the control group ($p = 0.055$).

On the right side, a trend towards significance was found for the 200-250 ms window ($F(4,59) = 2.140, p = 0.088$). This trend is due to the fact that the difference wave for late bilinguals was of smaller amplitude than for the control group ($p = 0.006$) and, to a degree, multilinguals ($p = 0.064$).

6.2.2.3 Discussion

The results of the analyses bring to light important differences in terms of the initial neurophysiological discrimination of the non-native contrast based on the amount of language learning experience. First of all, it is clear that late bilinguals exhibit different electrophysiological responses to the sound change compared to the other groups. In fact, while the other groups show either a slight or clear MMN, Figure 6.3 (see Section 6.2.2.1) shows that late bilinguals do not exhibit an MMN. Based on Figure 6.4 (see Section 6.2.2.1), it is not clear whether early bilinguals show an MMN either.

With respect to anteriority, it appears that the interaction between Anteriority and Group is mainly due to the fact that group differences in terms of the MMN are largely found in the

fronto-central electrodes. When each Laterality is analysed separately, the analysis reveals the same overall group differences obtained by the initial 3-way (Anteriority x Laterality x Group) ANOVA. More specifically, group differences (i.e. the amplitude of the difference wave is smaller for late bilinguals than for the other groups) are largely found in the fronto-central electrodes. As a result, it can be concluded that language learning experience does not seem to have an effect on the anteriority of the MMN.

With respect to the way group membership affects the laterality of the MMN, it seems that the most striking differences are observed in the midline electrodes. As was the case for the differences observed in the fronto-central electrodes, the significant effect of Group and the trends towards significance for this effect in the midline electrodes seem to reflect the overall group differences in terms of MMN amplitude that were revealed by the initial 3-way ANOVA. More specifically, it appears that late bilinguals are those who exhibit the smallest difference wave amplitude of all groups, probably because they do not show an MMN. A similar pattern is observed, though to a lesser degree, in the right electrodes.

Group differences were also found in the electrodes on the left side. Visual inspection of the waves for each group suggests that, in the left side electrodes, multilinguals and, to a certain extent, early bilinguals appear to have a larger MMN than the other groups. This difference is indeed statistically significant at 150-200 ms. Visual inspection of the waves also confirm that while the MMN observed for the monolinguals and the control group is mainly in the midline and the right side electrodes, multilinguals and, to some extent, early bilinguals have a more bilateral MMN. The results are in agreement with those of Shafer et al. (2004) who found that most differences between English and Hindi speakers with

respect to the discrimination of a contrast involving the retroflex category are in the midline and left side rather than on the right side. Since the activation of the left side auditory cortex (which can be evidenced by a greater left side activation) is thought to be involved in the processing of phonetic and phonemic sound differences (Näätänen et al., 1997; Näätänen, 2001; Shafer et al., 2004), the results indicate that more experienced language learners, such as multilinguals and bilinguals who have learned two languages from birth, process the sound change in a more linguistically relevant way compared to the other groups. In other words, they make more use of the linguistic sound-analysis system when processing the difference between the two sounds.

Based on what has been suggested in the literature, the group differences observed with respect to MMN amplitude and typology can be interpreted in terms of level of discrimination. Since the largest MMN amplitude and greatest number of electrode sites showing an MMN seem to be observed for multilinguals and, to some extent, early bilinguals, it can be suggested that these two groups can discriminate the non-native contrast better than the other groups. With respect to late bilinguals, this group of participants exhibited the smaller difference wave amplitude among the groups. While it is tempting to interpret these results as indicating that they have the lowest level of discrimination, it is important to consider the possibility that these participants simply processed the contrast at a different level. If these participants paid more attention to the stimuli, for instance, they could be exhibiting a P300 instead of an MMN. In fact, instead of showing a negativity to the deviant sound, they seem to show a positivity. It would therefore be interesting to investigate this issue in order to confirm whether a P300 is observed for this group.

While it is difficult to draw any clear conclusions regarding the latency of the onset and offset of the MMN by looking at 50 ms windows, it is interesting to note that although similar group differences hold for the earlier time windows (up to 300 ms), different results are obtained for the 300-350 ms window. For that later window, the MMN for multilinguals is no longer significantly greater than for any other group. In fact, the amplitude of the MMN for multilinguals is smaller than for that of other groups (i.e. control, early bilinguals and late bilinguals) as revealed by the various analyses. This could suggest an earlier MMN offset for multilinguals. It would be interesting to see if this claim could be confirmed when using smaller time windows.

It is also interesting to note that the control group also exhibits fairly good neurophysiological discrimination of the contrast. This is shown by an MMN of significantly greater amplitude for various time windows. This is not so surprising considering that this group is made up of participants who would have qualified to be in any of the other groups. As a result, the initial discrimination abilities of the control group are not really of interest. Rather, it will be interesting to see how this group compares to the other groups with respect to the Pre-Test – Post-Test differences in order to see which group(s), as a result of training, show(s) significantly greater improvement than the control group which did not receive any training.

6.2.3 Post-Test

6.2.3.1 Observations

Visual inspection of the average waves for each group, as presented in Figures 6.7 through 6.11, suggests that all groups seem to exhibit an MMN at Post-Test. As was the case for the

Pre-Test results, some group differences can also be observed at Post-Test. Once again the amplitude of the MMN appears to be larger for multilinguals compared to the other groups. Furthermore, as can be seen in Figure 6.12, multilinguals also appear to have a greater MMN amplitude on the left compared to the other groups, especially in F3 and FC3. Various statistical analyses were performed in order to determine whether the differences are significant.

Figure 6.7 – Control Group at Post-Test

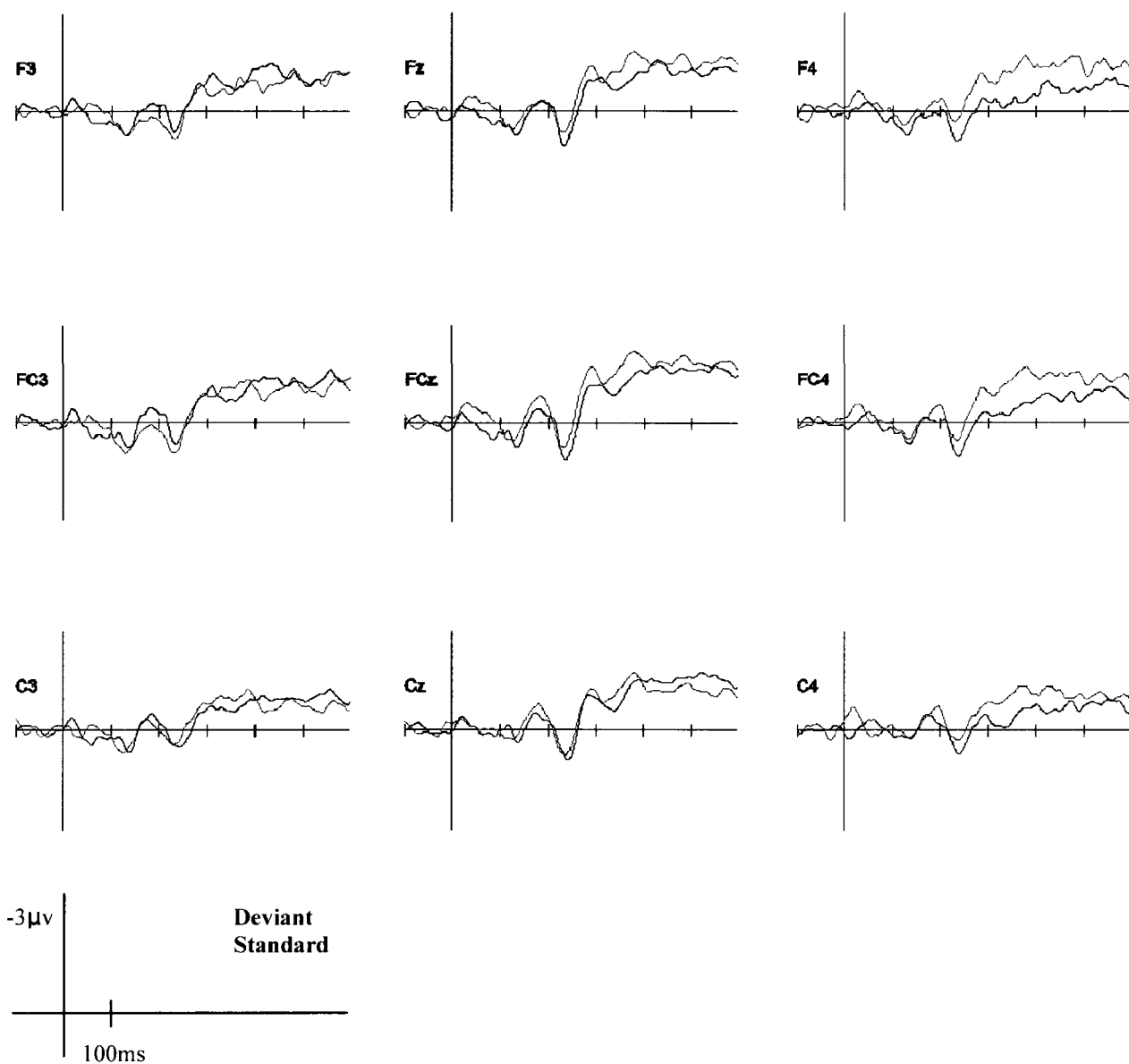


Figure 6.8 – Monolinguals at Post-Test

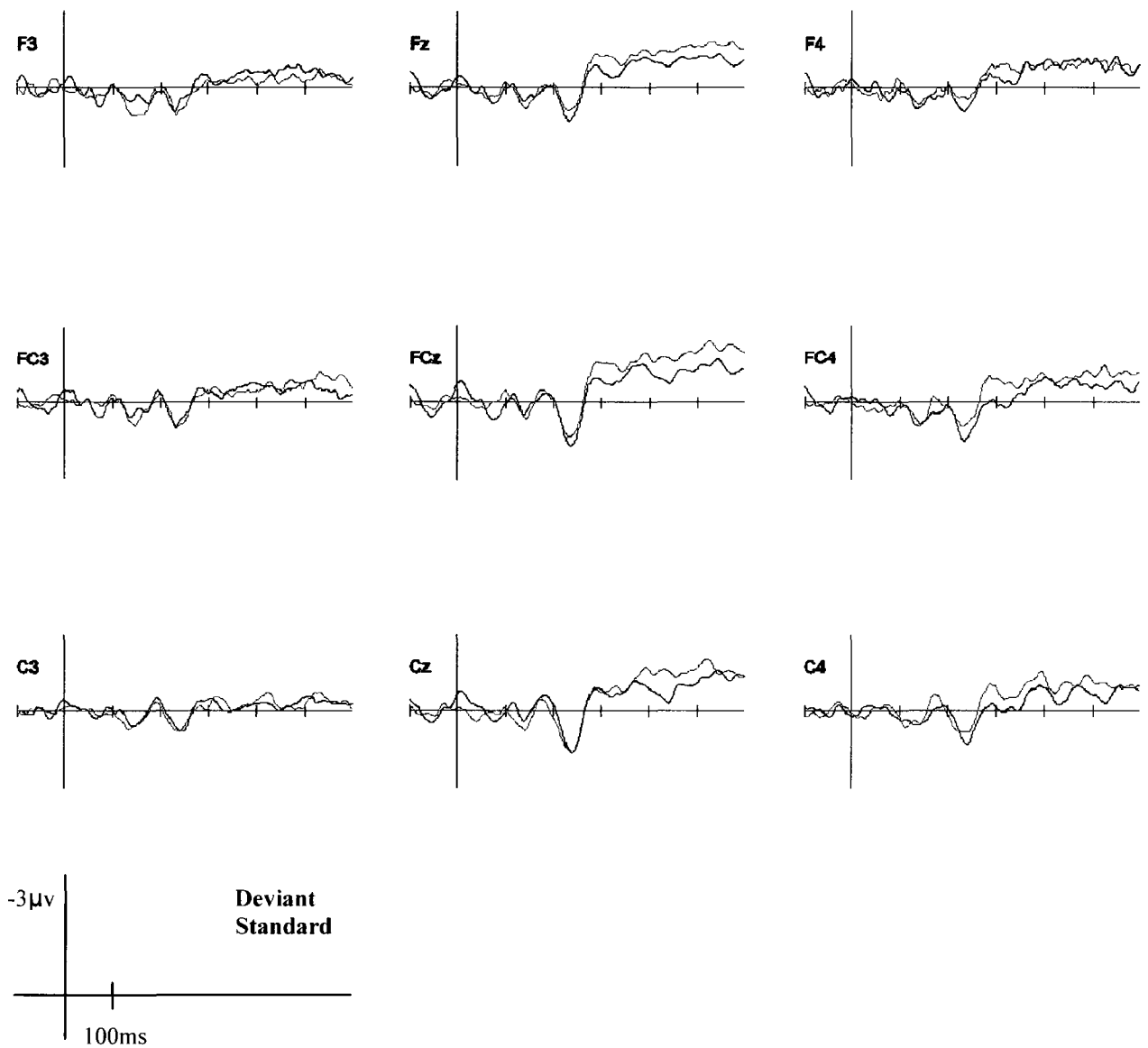


Figure 6.9 – Late Bilinguals at Post-Test

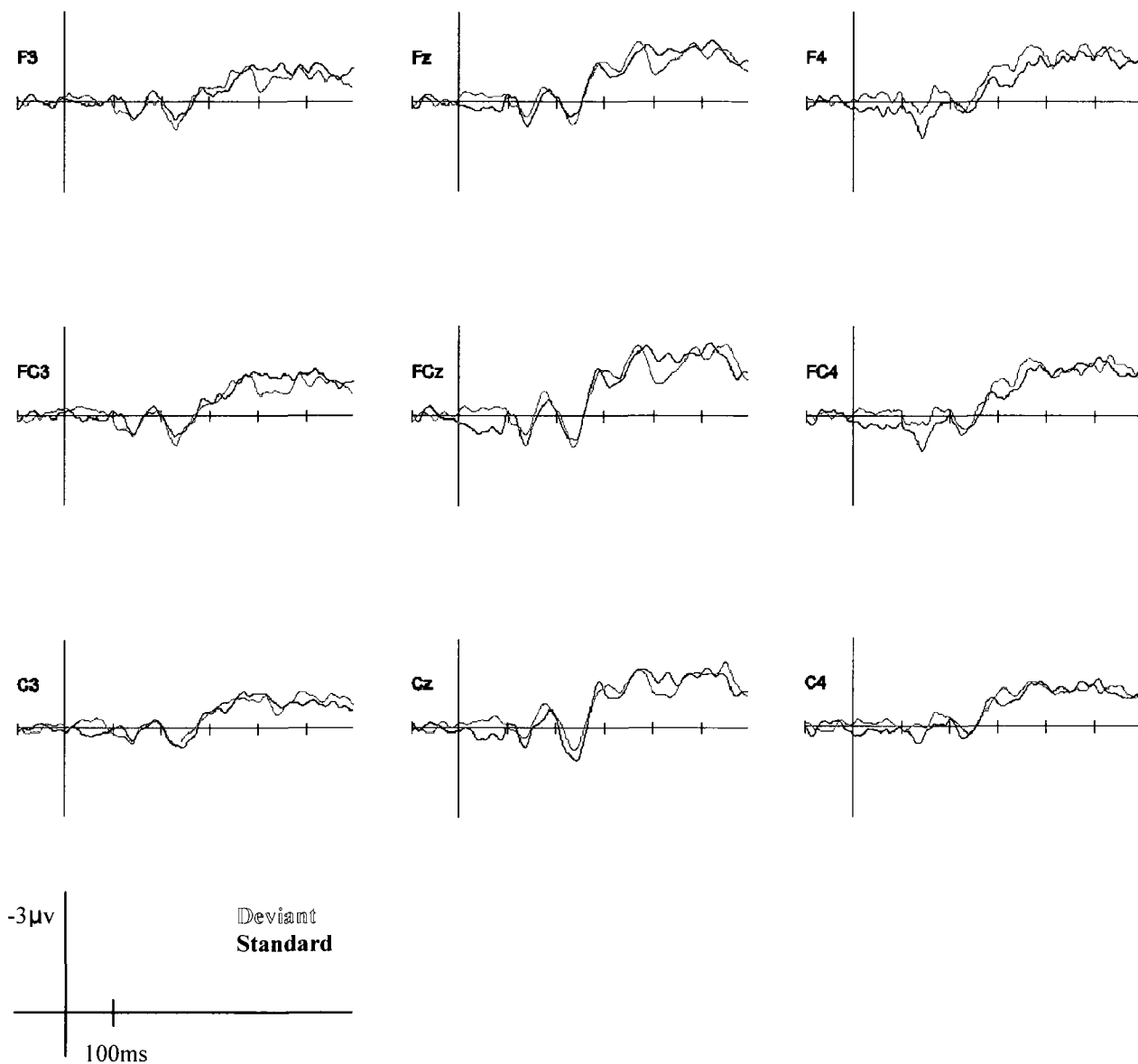


Figure 6.10 – Early Bilinguals at Post-Test

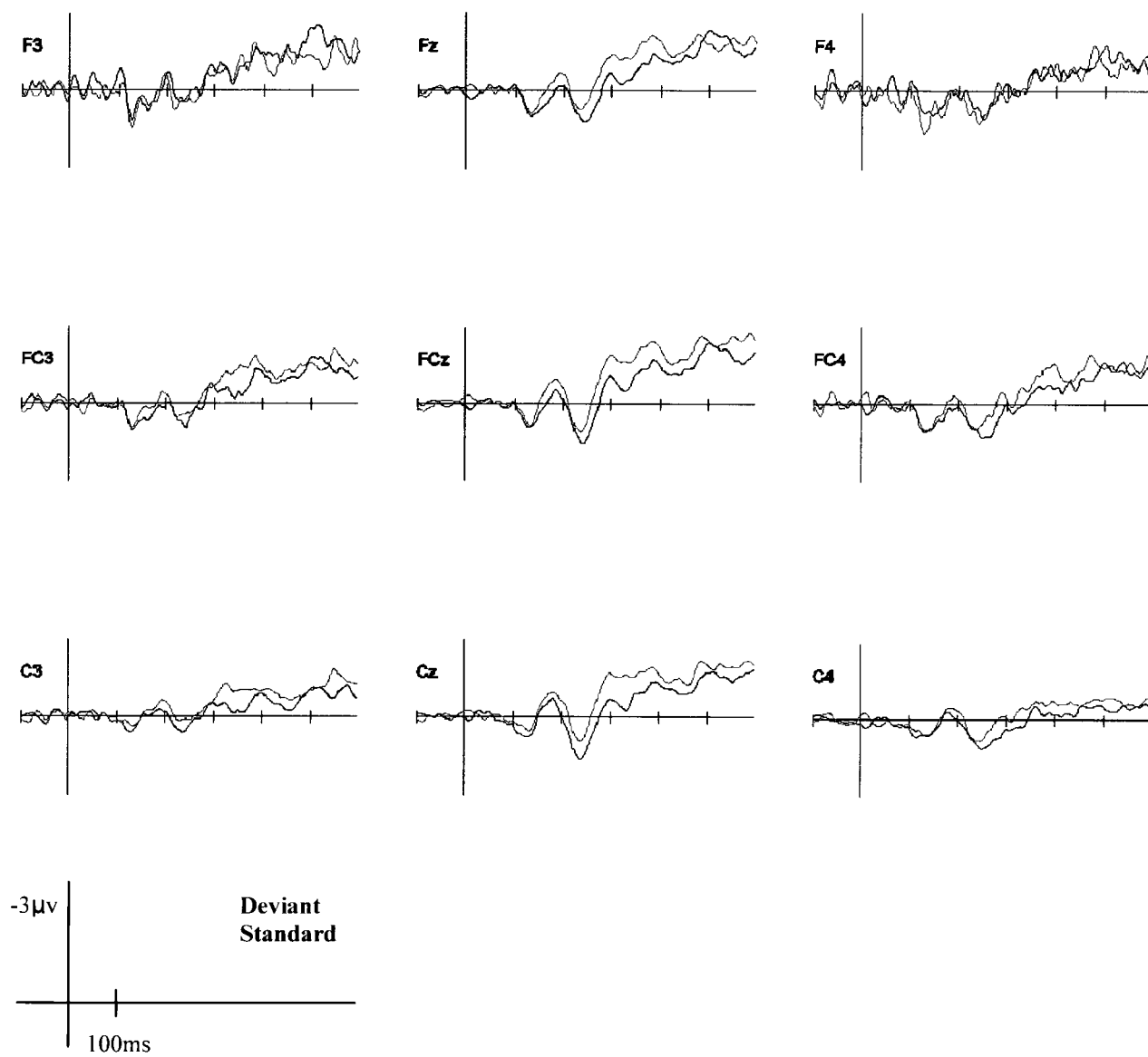


Figure 6.11 – Multilinguals at Post-Test

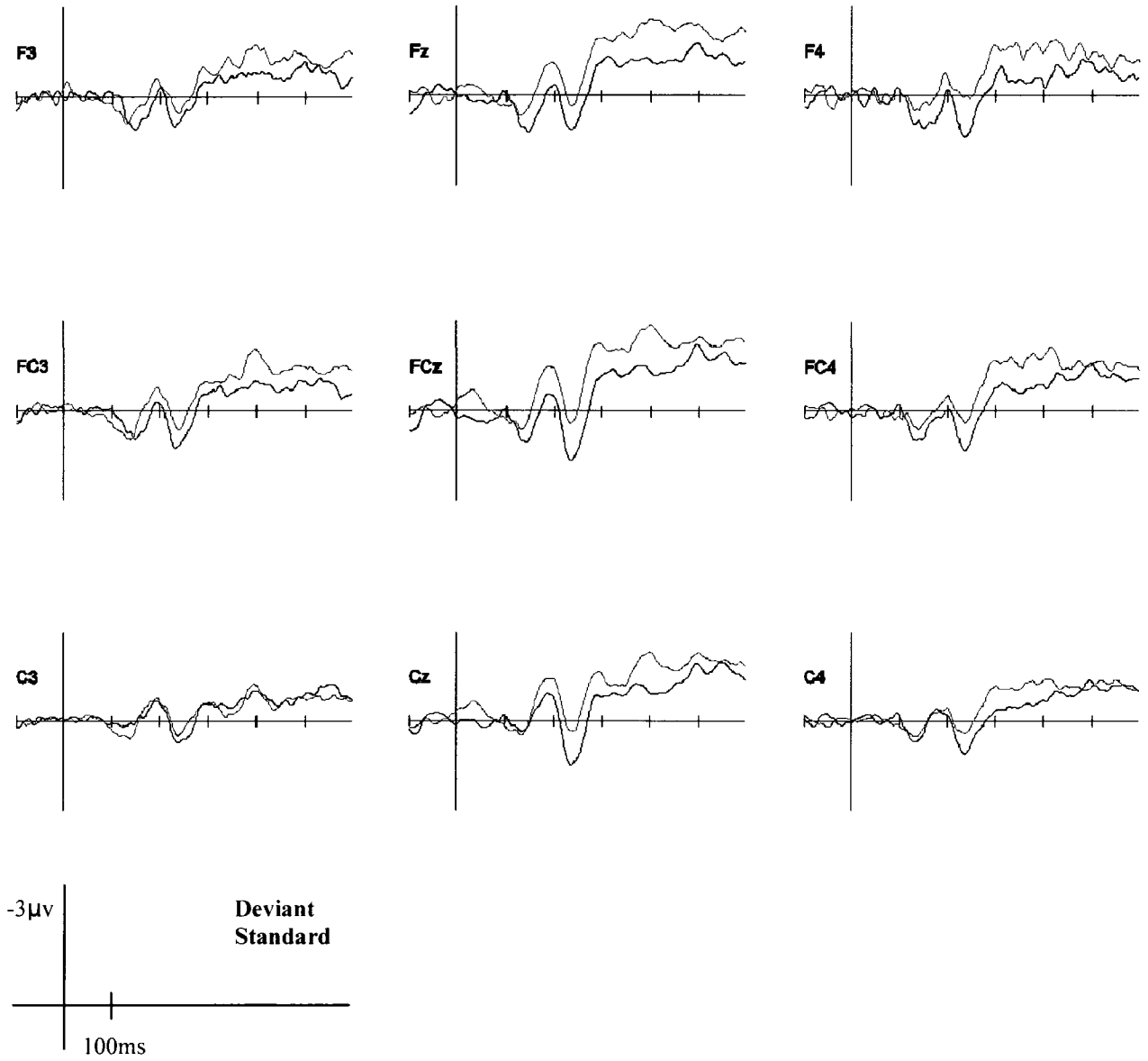
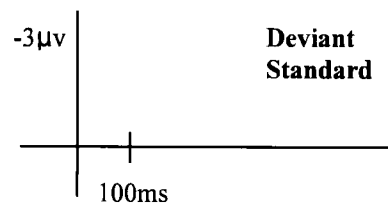
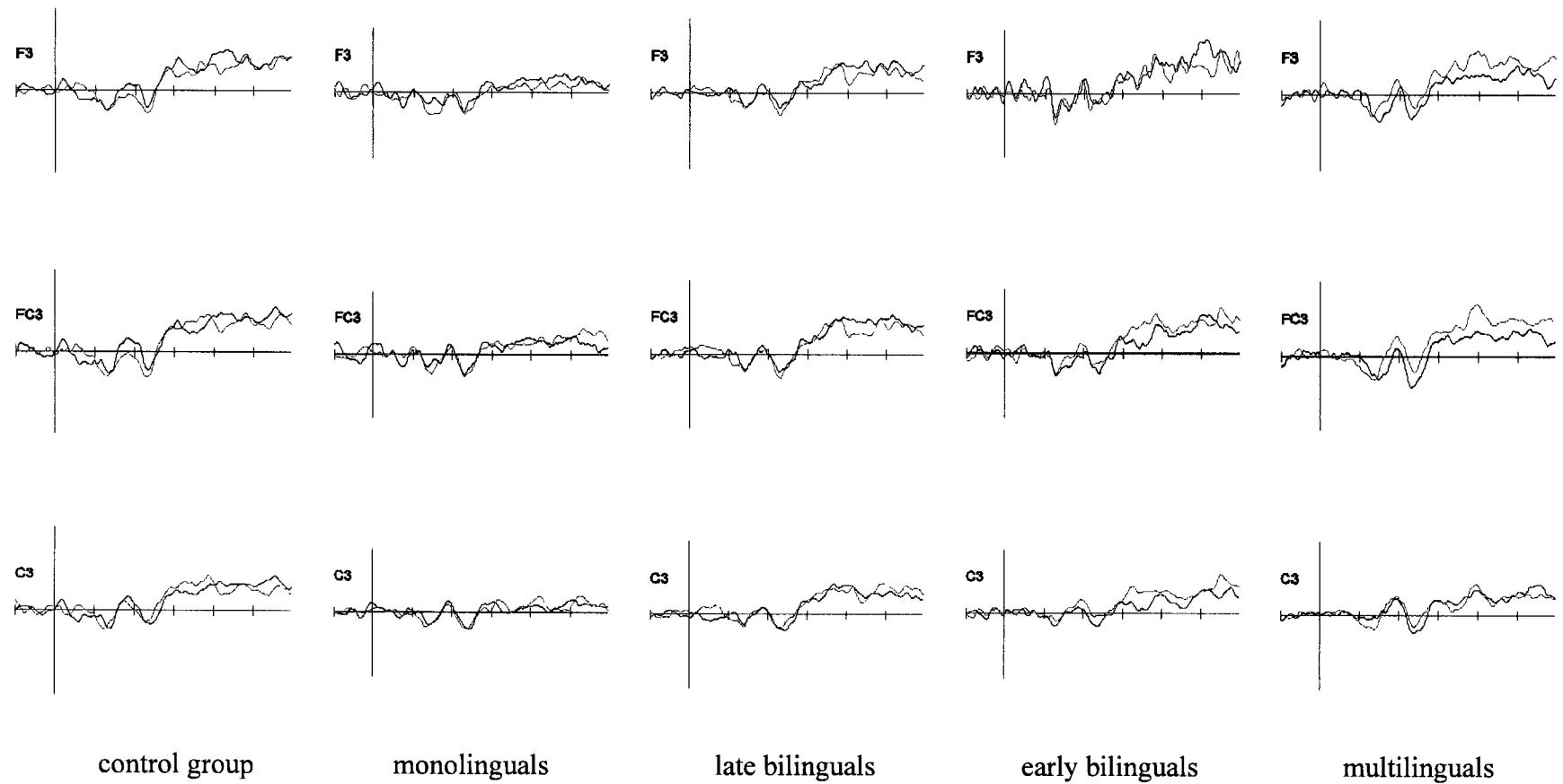


Figure 6.12 – Left Electrodes for all Groups at Post-Test



6.2.3.2 Statistical Analysis

An initial repeated measures ANOVA was performed on the difference waves at Post-Test with Anteriority and Laterality as within-subject factors and Group as between-subject factor. The results are reported in Table 6.5.

Table 6.5 – Anteriority x Laterality x Group Repeated Measures ANOVA

Time window	Factor	df	F	<i>p</i>
100-150 ms	Laterality	2	4.282	0.016*
150-200 ms	Laterality	2	3.711	0.028*
200-250 ms	Laterality	2	3.664	0.029*
250-300 ms	Laterality	2	6.354	0.002**
300-350 ms	Laterality	2	4.850	0.01**
350-400 ms	Laterality	2	3.775	0.026*

As shown in Table 6.5, the analysis revealed a significant effect of Laterality for each of the time windows analysed (100-150 ms: $F(2,110) = 4.282$, $p = 0.016$; 150-200 ms: $F(2,110) = 3.711$, $p = 0.028$; 200-250 ms: $F(2,110) = 3.664$, $p = 0.029$; 250-300 ms: $F(2,110) = 6.354$, $p = 0.002$; 300-350 ms: $F(2,110) = 4.850$, $p = 0.01$; 350-400 ms: $F(2,110) = 3.775$, $p = 0.026$). Pairwise comparisons reveal that the amplitude of the difference wave was significantly smaller in the left electrodes compared to the midline and the right electrodes in most of the time windows (100-150 ms: midline: $p = 0.051$, right: $p = 0.019$; 150-200 ms: midline: $p = 0.011$, right: $p = 0.057$; 200-250 ms: midline: $p = 0.01$, right: $p = 0.073$; 250-300 ms: midline: $p = 0.003$, right: $p = 0.007$; 300-350 ms: midline: $p = 0.016$, right: $p = 0.013$; 350-400 ms: midline: $p = 0.04$, right: $p = 0.022$).

While the interaction between Group and Laterality did not turn out to be significant for any of the time windows, further analyses were nevertheless performed in order to look for any group differences at each laterality. There are several reasons to perform these analyses. First of all, it was hypothesised that group effects would be found across the different lateralities. In fact, such group differences were indeed observed at Pre-Test. Finally, as can be seen in Figure 6.12, some differences among the groups are apparent upon visual inspection of the waves, especially on the left side.

In order to determine whether Group has an effect on the amplitude of the MMN at each laterality, a 1-way ANOVA was performed on each laterality. The results of the analysis revealed no significant Group effect and only one trend towards significance for the midline electrodes at 250-300 ms ($F(4, 59) = 2.088, p = 0.095$). Pairwise comparisons revealed that the amplitude of the difference wave was larger for multilinguals compared to monolinguals ($p = 0.037$), late bilinguals ($p = 0.013$) and, although it is only a trend, compared to the control group as well ($p = 0.101$). Moreover, although it does not reach significance, the amplitude of the difference waves for early bilinguals was also, to some extent, greater than for late bilinguals ($p = 0.093$).

While the previous analysis, which combined F, FC and C when looking for group differences at each laterality, did not find any significant effect of Group in the left electrodes, visual inspection of the waves in Figure 6.12 suggests that group differences are mostly found in F3 and FC3. As a result a 1-way ANOVA was performed on these two electrodes combined. A Group effect nearly reached significance at 150-200 ms ($F(4,59) = 2.495, p = 0.053$). Pairwise comparisons confirmed that the amplitude of the difference

wave for multilinguals was significantly greater compared to monolinguals ($p = 0.045$) and the control group ($p = 0.005$) and, to some extent, late bilinguals ($p = 0.057$). Moreover, the amplitude of the difference wave of early bilinguals was also greater than for the control group ($p = 0.06$), although not in a statistically significant way.

6.2.3.3 Discussion

Contrary to what transpired at Pre-Test, no main effect of Group was found at Post-Test. The only significant effect that emerged from the analysis was one of Laterality. This effect was due to the fact that the amplitude of the MMN was significantly larger in the right side and in the midline electrodes than in the left side electrodes. Although the same pattern was also observed at Pre-Test, the difference between the lateralities was only significant at Post-Test. This is most likely due to the fact that the amplitude of this midline and right lateralised MMN observed in all groups increased to the point where it was significantly larger than on the left at Post-Test.

It is important to note, however, that when looking at each laterality individually, some group differences did emerge from the analysis. Once again, differences are mainly found in the midline and the left electrode sites. First of all, in the midline electrodes, while the effect of Group did not reach statistical significance, pairwise comparisons suggested that the amplitude of the MMN for multilinguals was larger than for monolinguals, late bilinguals and the control group. The amplitude of the MMN for early bilinguals was also, to a degree, larger than that of late bilinguals. These results suggest that language learning experience does affect the discrimination abilities of the non-native contrast at Post-Test such that having learned three or more languages enhances perceptual abilities. Having

learned two languages from birth also appears to have a positive effect on perceptual abilities after training.

A more thorough analysis of the left laterality also revealed an interesting pattern of group differences. The analysis confirms what is clear upon visual inspection, namely that, in FC3 and F3, multilinguals exhibited a larger MMN than monolinguals, the control group, and late bilinguals. Early bilinguals also seemed to have a greater MMN than the control group at these electrode sites.

As was suggested for the results at Pre-Test, a larger MMN and a more bilateral one (as opposed to a right lateralised one) can be interpreted as a sign of greater perceptual sensitivity to the sound change in the contrast. Once again, it suggests that having learned three or more languages and, to a degree, having learned two languages from birth, may enhance an individual's ability to perceive a non-native contrast.

6.2.4 Learning Rates: Pre-Test – Post-Test Differences

6.2.4.1 Observations

Since it was hypothesised that language learning experience would have an impact on learning rates, it was important to look not only at the Pre-Test and Post-Test results independently, but also at the differences in electrophysiological responses between before and after training. In order to look into potential differences among groups, a measure of the amplitude change in the difference wave at Pre-Test and Post-Test was obtained by subtracting the average difference wave at Pre-Test from the average difference wave at

Post-Test for each individual. Various statistical analyses were performed in order to determine whether any differences were significant.

6.2.4.2 Statistical Analysis

An initial ANOVA was performed on the “difference” difference waves with Anteriority and Laterality as within-subject factors and Group as between-subject factor. The results are presented in Table 6.6.

Table 6.6 – Anteriority x Laterality x Group Repeated Measures ANOVA

Time window	Factor	df	F	p
100-150 ms	Laterality	2	2.514	0.086
200-250 ms	Laterality	2	2.824	0.064
	Anteriority*Laterality	4	2.082	0.084
	Anteriority*Laterality*Group	16	1.567	0.079
250-300 ms	Laterality	2	2.440	0.092
	Anteriority*Laterality*Group	16	2.335	0.003**
350-400 ms	Anteriority*Laterality*Group	16	1.581	0.075

As can be seen in Table 6.6, various trends towards significance were found for Laterality. Pairwise comparisons confirm that the changes in amplitude were smaller on the left side than on the right side and in the midline. At 100-150 ms, the amplitude in the right electrodes was greater than both the left side ($p = 0.073$) and the midline electrodes ($p = 0.088$). At 200-250 ms, the amplitude was significantly greater in the midline electrodes compared to the left side electrodes ($p = 0.022$). Finally, at 200-250 ms the amplitude in the midline electrodes was also significantly greater than in the left side electrodes ($p = 0.029$).

Based on the significant interactions and trends toward significance for the interaction between Laterality, Anteriority and Group (200-250 ms: $F(16,220) = 1.567, p = 0.079$; 250-300 ms: $F(16,220) = 2.335, p = 0.003$; 300-350 ms: $F(16,220) = 1.581, p = 0.075$) and based on the hypotheses regarding a potential Group effect on Laterality, a 1-way ANOVA was performed on each laterality in order to look for any effect of Group. The analysis found no Group effect for any of the levels of Laterality. A 1-way ANOVA was therefore also performed on each Anteriority in order to determine if the three-way interaction was due to the interaction of Group and Anteriority. No Group effect was found for any of the levels of Anteriority either.

Based on the fact that group differences are visually perceptible from the waves across the different groups and on the fact that various experiments have focused on Cz when analysing ERP MMN data (Sharma & Dorman, 1999; Tampas et al., 2005; Tremblay and Kraus, 2002), a 1-way ANOVA was performed on the “difference” difference waves for Cz. The results are presented in Table 6.7.

Table 6.7 – 1-way ANOVA on the Pre-Test – Post-Test Difference for Cz

Electrode	Time window	df	F	<i>p</i>
Cz	200-250 ms	4	3.278	0.018*
Cz	250-300 ms	4	4.856	0.002**
Cz	300-350 ms	4	2.812	0.034*
Cz	350-400 ms	4	3.315	0.092

A main effect of Group, or trend towards significance, was found at Cz for the following windows: 200-250 ms , ($F(4,59) = 3.278, p = 0.018$), 250-300 ms ($F(4,59) = 4.856, p =$

0.002), 300-350 ms ($F(4,59) = 2.812, p = 0.034$) and 350-400 ms ($F(4,59) = 3.315, p = 0.092$). Pairwise comparisons suggested that the increase in the MMN amplitude after training was more substantial for multilinguals and both groups of bilinguals compared to monolinguals and the control group. At 200-250 ms, the amplitude of the change for monolinguals was smaller than for late bilinguals ($p = 0.012$), multilinguals ($p = 0.01$) and, to some extent, early bilinguals ($p = 0.103$). The change in amplitude was also significantly smaller for the control group compared to late bilinguals ($p = 0.018$) and multilinguals ($p = 0.017$). At 250-300 ms, the amplitude of the change for monolinguals was smaller than for late bilinguals ($p = 0.030$), early bilinguals ($p = 0.036$) and multilinguals ($p < 0.001$). The amplitude change was also smaller for the control group compared to these groups (late bilinguals: $p = 0.054$; early bilinguals: $p = 0.047$; multilinguals: $p = 0.001$). As for the 300-350 ms window, the amplitude of the change for monolinguals was smaller than for late bilinguals ($p = 0.043$) and multilinguals ($p = 0.023$). The change in amplitude was also significantly smaller for the control group compared to late bilinguals ($p = 0.025$), multilinguals ($p = 0.013$) and, to some extent, early bilinguals ($p = 0.098$). Finally, the pairwise comparisons for the trend towards significance at 350-400 ms is due to the fact that the amplitude change was smaller for monolinguals and the control group compared to the multilinguals ($p = 0.01$ and $p = 0.039$ respectively). Moreover, although the difference was not significant, the change in amplitude also appeared to be smaller for monolinguals compared to early bilinguals ($p = 0.1$).

6.2.4.3 Discussion

The analysis revealed a main effect of Laterality on the changes in amplitude of the difference waves between Pre-Test and Post-Test. Overall, the amplitude of the difference

waves increased more on the right side, and, to some extent, in the midline, than on the left side. This confirms the claim put forward in Section 6.2.3.3 about the Post-Test results with regards to the effect that, after training, the increase in amplitude of the MMN in the right side and midline electrodes increased to the extent that the difference between right and midline electrodes on the one hand and the left electrodes on the other became significant.

It was hypothesised that language learning experience would have an impact on learning rates. At the electrophysiological level, learning to discriminate a non-native contrast was manifested by an increase in the amplitude of the MMN and, possibly, by a change in its typology at the scalp. Since various interactions were found between Anteriority, Laterality and Group, various analyses were performed in order to find out what caused these interactions to be significant. The analysis found a main effect of Group for Cz at various time windows. Pairwise comparisons suggested that the increase in the MMN amplitude after training was more substantial for multilinguals and both groups of bilinguals compared to monolinguals and the control group. Moreover, monolinguals were the only group who did not differ from the control group in terms of change in amplitude or, put differently, in terms of learning. As a result, it can be concluded that language learning experience does have an effect on learning rates. Thanks to training, the increase in electrophysiological response signalling the discrimination of a non-native contrast was more significant in individuals who have learned two languages or more compared to individuals who have only learned one language. While the analysis revealed that language learning experience had an effect on the increase in amplitude of the MMN as a result of learning, for now, it is not possible to make any claims about the way language learning

experience affects the way learning manifests itself by a change in the typology of the MMN.

6.2.5 Test of Transfer

6.2.5.1 Observations

With respect to the electrophysiological responses to the sound change in the transfer contrast, it can be noted that most groups appear to exhibit, to varying degrees, an MMN. Possibly, the MMN could be of larger amplitude for monolinguals, late bilinguals and multilinguals. Various analyses were performed in order to determine whether any differences reach statistical significance.

Figure 6.13 – Control Group for the Test of Transfer

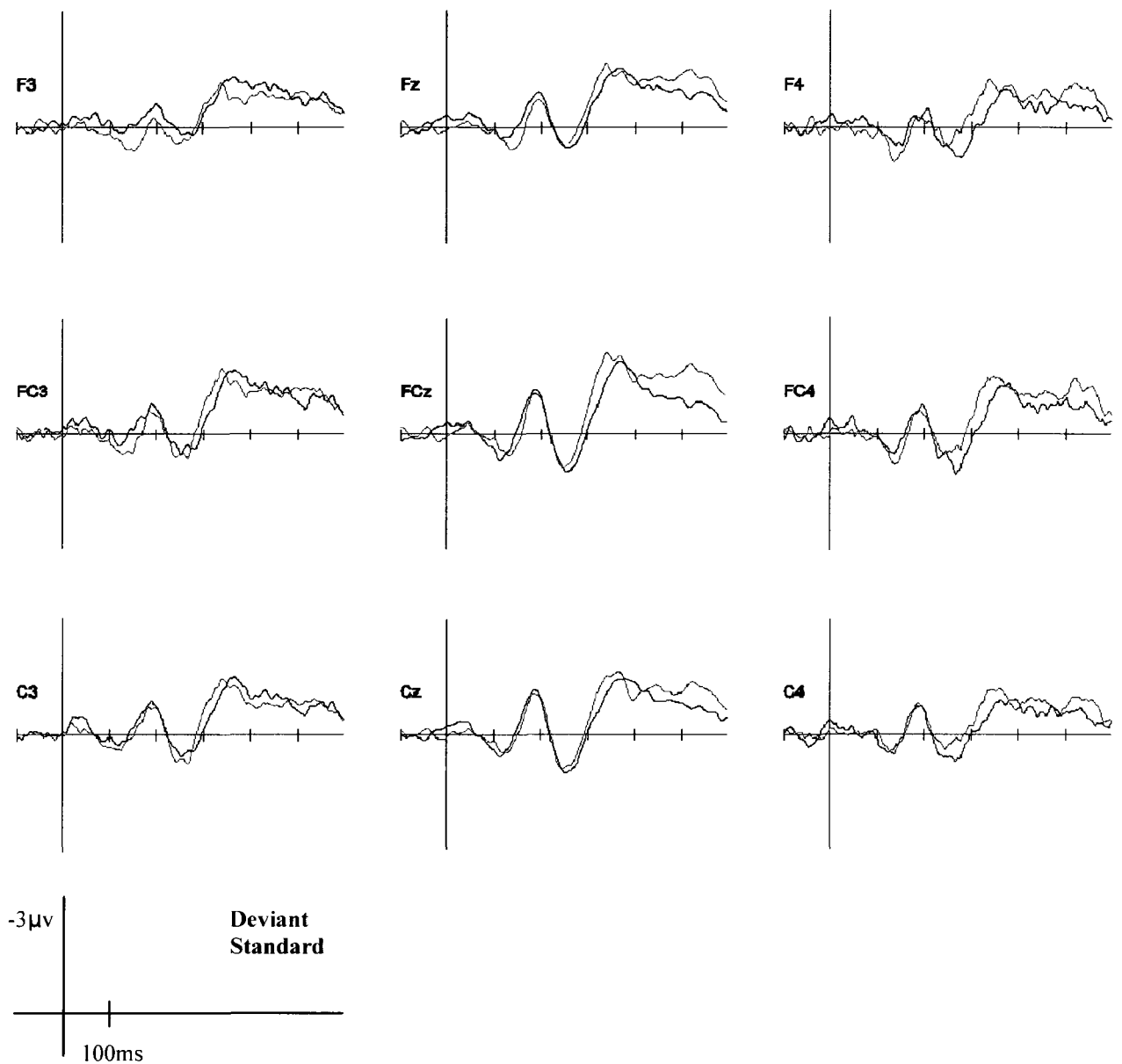


Figure 6.14 – Monolinguals for the Test of Transfer

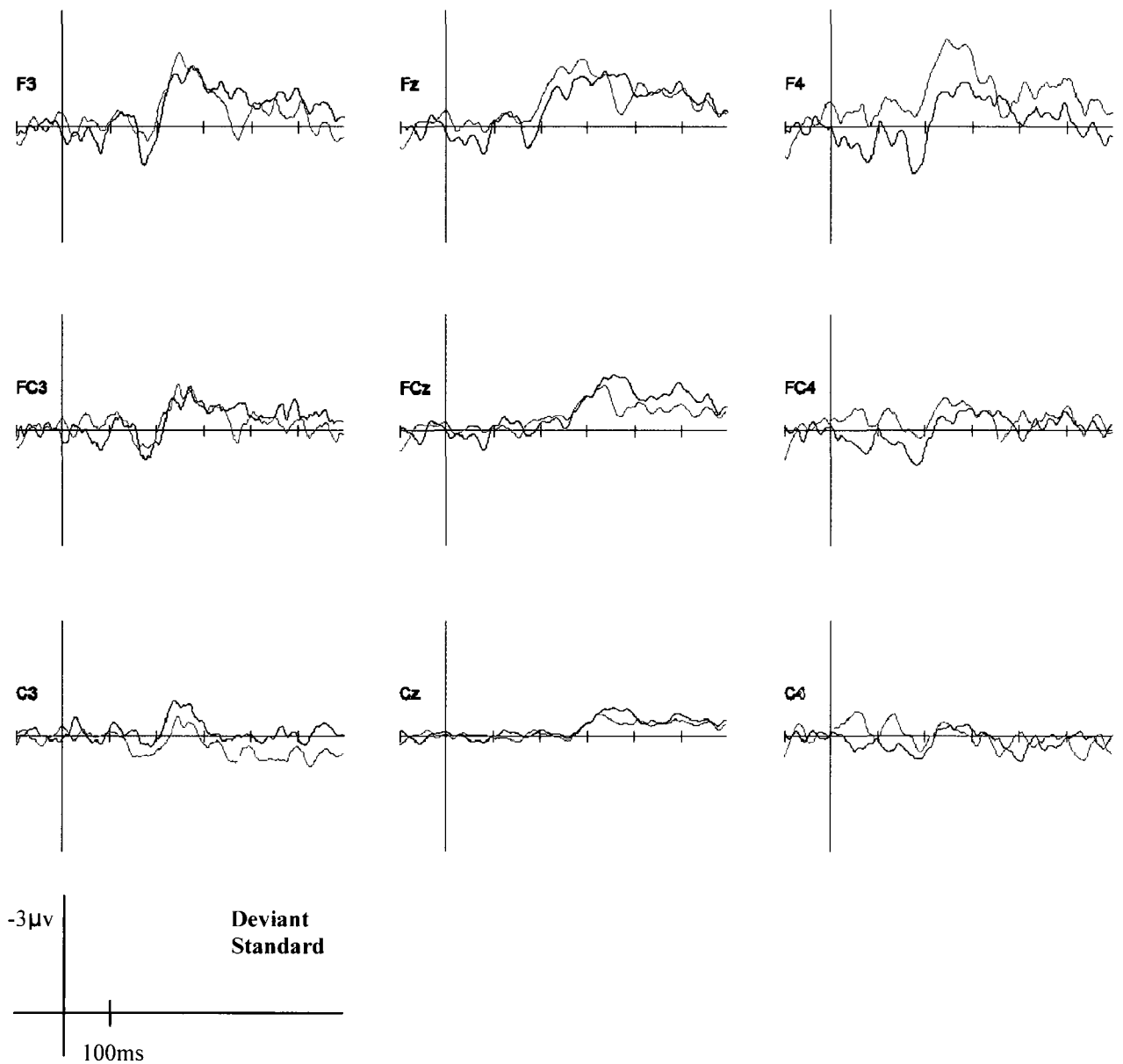


Figure 6.15 – Late Bilinguals for the Test of Transfer

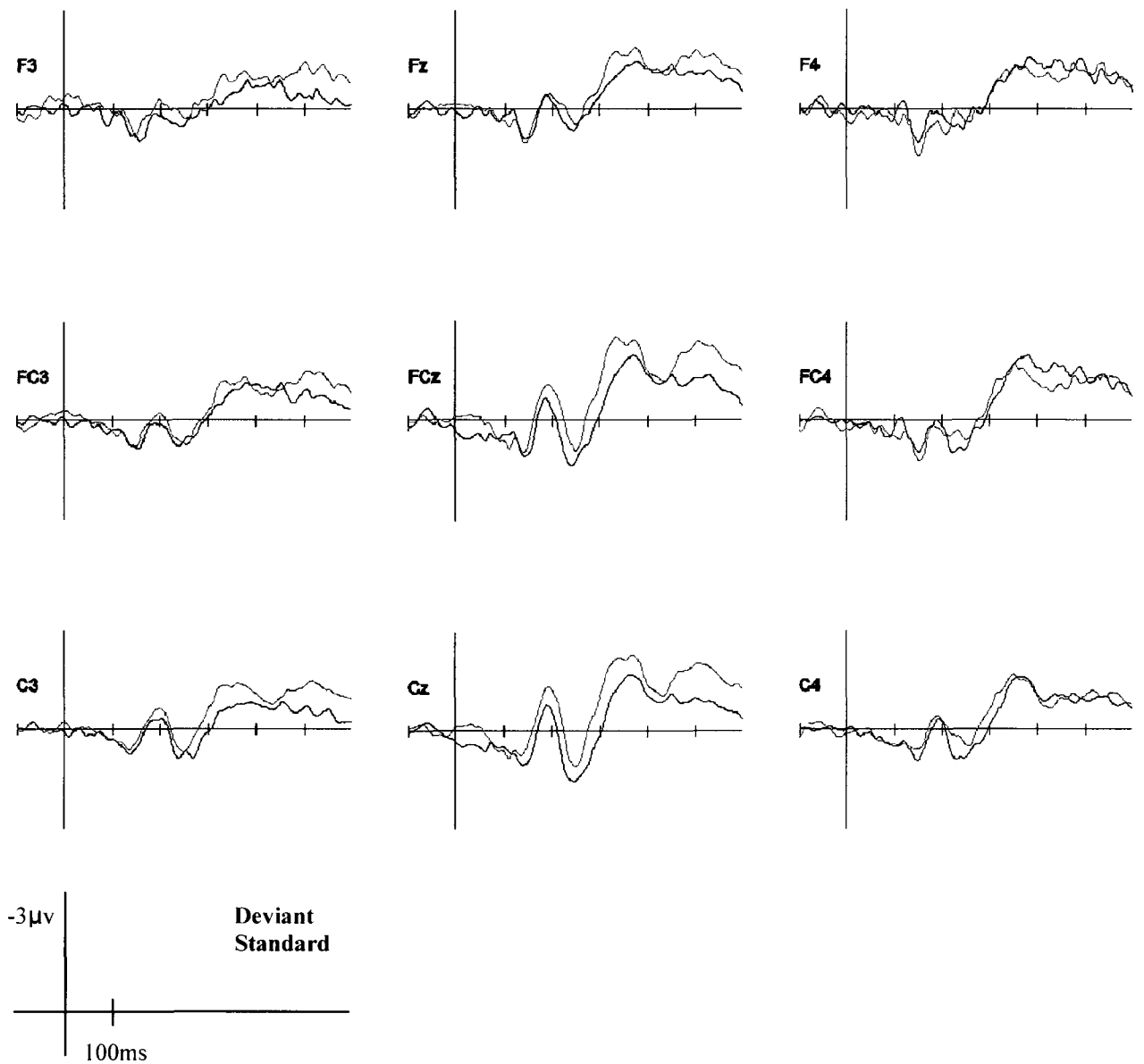


Figure 6.16 – Early Bilinguals for the Test of Transfer

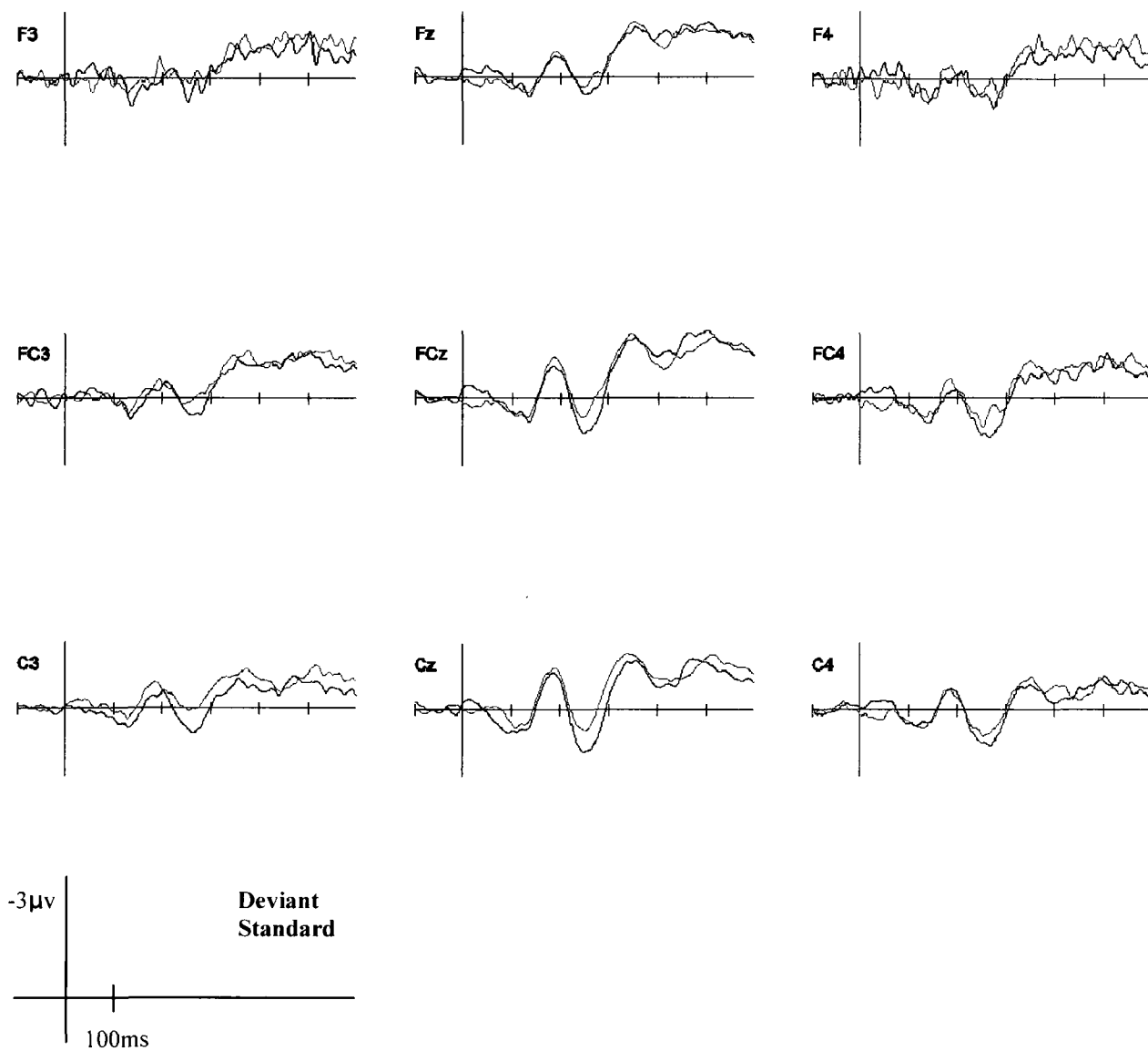


Figure 6.17 – Multilinguals for the Test of Transfer

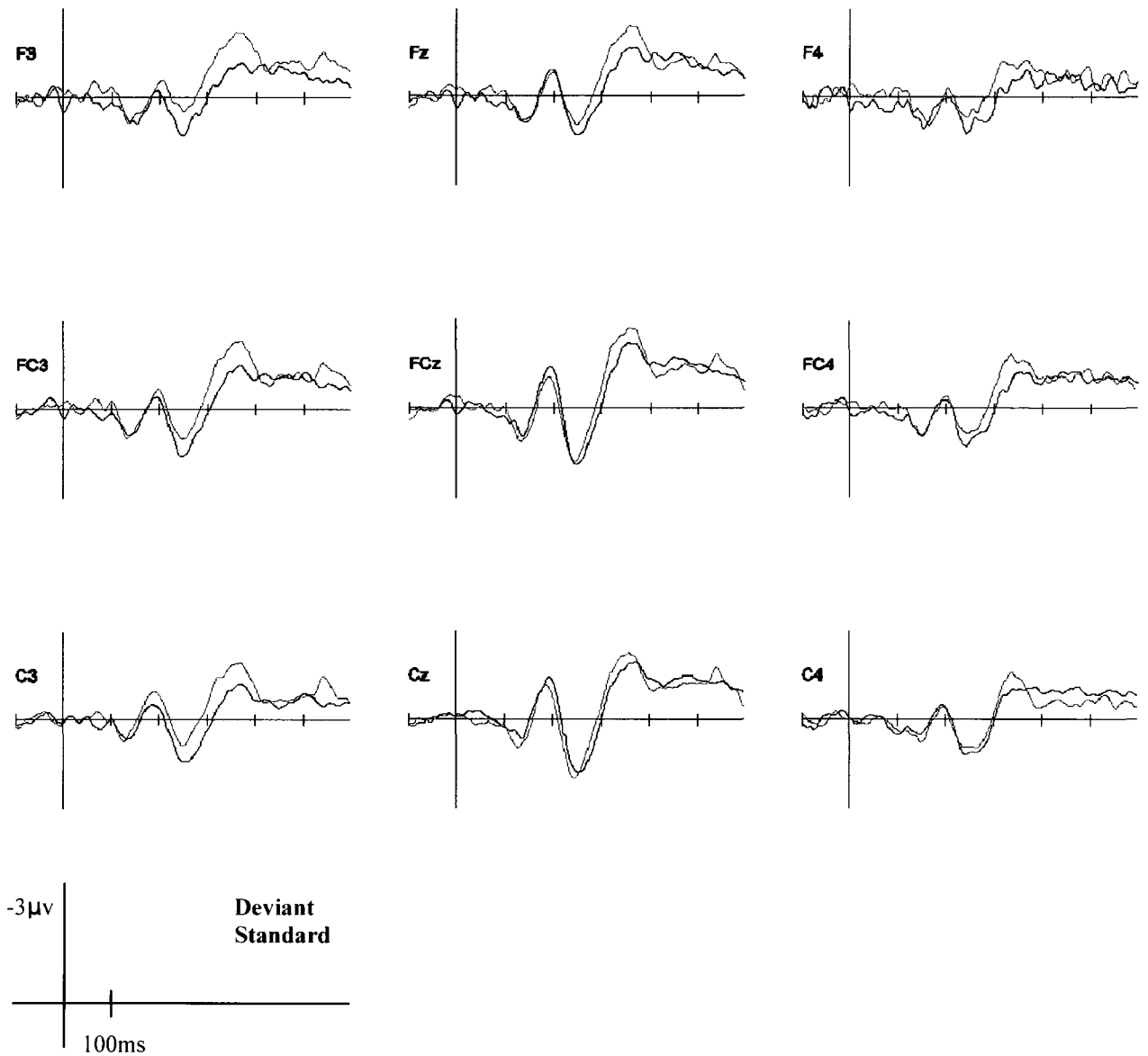
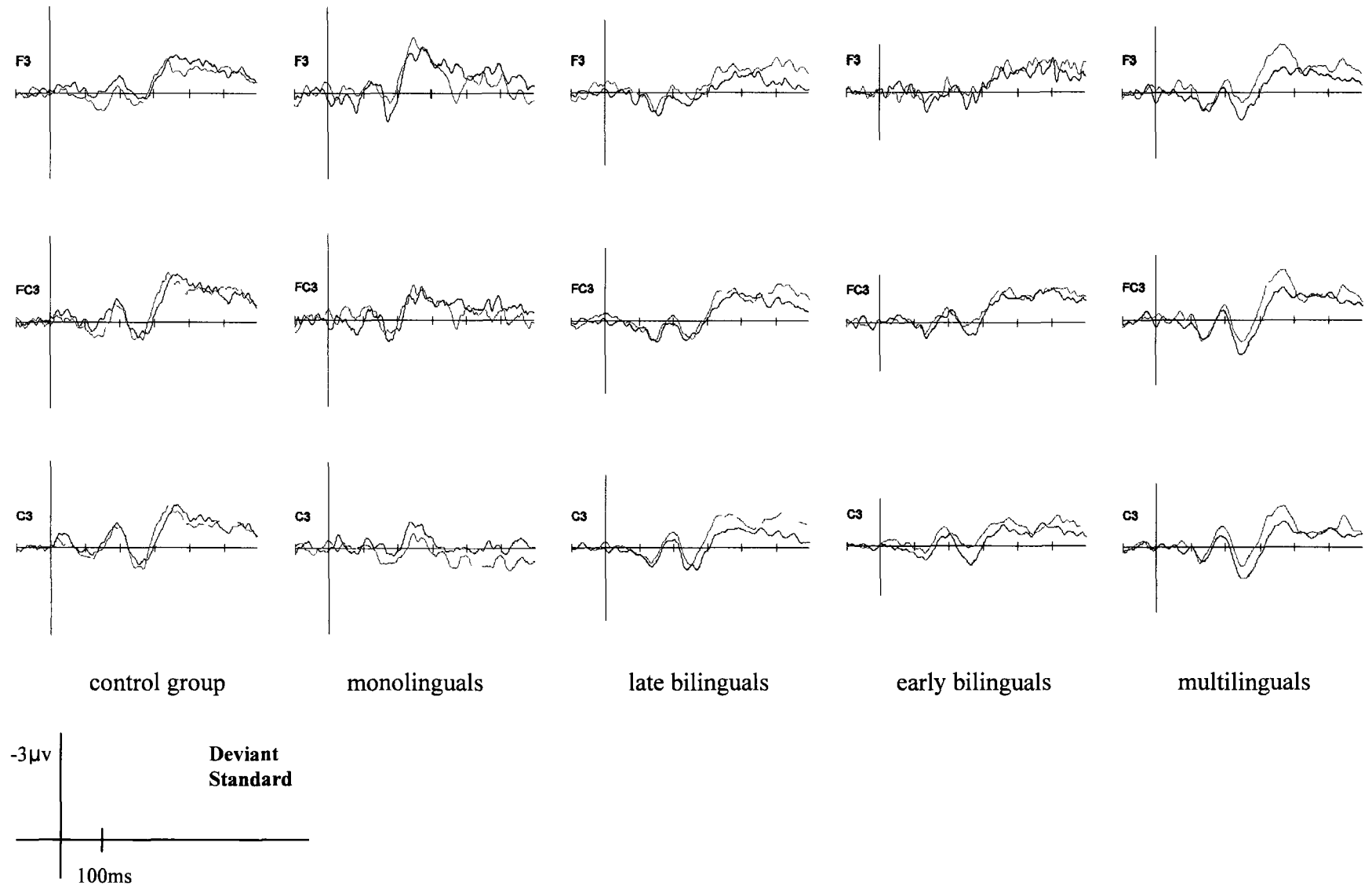


Figure 6.18 – Left Electrodes for all Groups for the Test of Transfer



6.2.5.2 Statistical Analysis

An initial repeated measures ANOVA was performed on the difference waves for the Test of Transfer with Anteriority and Laterality as within-subject factors and Group as between-subject factor. The results are presented in Table 6.8.

Table 6.8 – Anteriority x Laterality x Group Repeated Measures ANOVA

Time window	Factor	df	F	p
100-150 ms	Laterality*Group	8	2.463	0.017*
150-200 ms	Laterality*Group	8	2.311	0.025*
200-250 ms	Laterality*Group	8	2.486	0.016*
	Anteriority*Laterality*Group	16	2.127	0.008**
250-300 ms	Anteriority*Laterality	4	2.482	0.045*
300-350 ms	Anteriority*Laterality	4	2.438	0.048*
350-400 ms	Laterality*Group	8	2.165	0.036*

While no Group effect was found, Group did interact significantly with Laterality (100-150 ms: $F(8,110) = 2.463$, $p = 0.017$; 150-200 ms: $F(8,110) = 2.311$, $p = 0.025$; 200-250 ms: $F(8,110) = 2.486$, $p = 0.016$; 350-400 ms: $F(8,110) = 2.165$, $p = 0.036$) and, for one time window, with both Laterality and Anteriority ($F(16,220) = 2.127$, $p = 0.008$). The interaction between Group and Laterality was explored further by performing a 1-way ANOVA on each laterality in order to look for any effect of Group. The results are presented in Table 6.9.

Table 6.9 – Effect of Group for Left, Midline and Right Electrodes

Laterality	Time window	df	F	p
Left	350-400 ms	4	2.249	0.075
Right	100-150 ms	4	2.274	0.073
	150-200 ms	4	2.490	0.054

Looking at pairwise comparisons, the trend towards significance for a Group effect on the left ($F(4,59) = 2.249, p = 0.075$) seems to be due to the fact that the amplitude of the difference wave for monolinguals was smaller than for multilinguals ($p = 0.013$) and, although not significantly, also smaller than for late bilinguals ($p = 0.082$) and early bilinguals ($p = 0.097$). Moreover, the amplitude of the difference wave for multilinguals was significantly greater than for the control group ($p = 0.013$).

On the right, the trend towards significance for a Group effect at 100-150 ms ($F(4,59) = 2.274, p = 0.073$) and 150-200 ms ($F(4,59) = , p = 0.054$) appears to be due to the fact that the amplitude of the difference wave was greater for monolinguals than for all other groups (100-150 ms: late bilinguals: $p = 0.01$; early bilinguals: $p = 0.041$; multilinguals: 0.1; control group: $p = 0.015$; 150-200 ms: late bilinguals: $p = 0.012$; early bilinguals: $p = 0.06$; multilinguals: $p = 0.021$; control group: $p = 0.009$).

6.2.5.3 Discussion

Overall, no main effect of Group was found with respect to the amplitude of the MMN for the Test of Transfer. When each laterality is analysed separately, however, some group differences emerged. On the left, multilinguals were the only group who had a significantly larger MMN than both monolinguals and the control group. Bilinguals (late and early) also seemed to have a larger MMN on the left than monolinguals, although the difference failed to reach statistical significance. On the right, on the other hand, the analysis indicated that monolinguals had a greater MMN than the other groups.

Again, these differences in terms of the lateralisation of the MMN could indicate differences in terms of processing. The fact that multilinguals and, to some extent, bilinguals (late and early), had a greater MMN amplitude on the left than monolinguals (and the control group) could be interpreted as a sign that more experienced language learners process the sound difference at a more phonetic level than less experienced learners. In fact, this claim is supported by the fact that monolinguals had a significantly greater MMN amplitude on the right than the other group and a right lateralised MMN is indicative of acoustic sound discrimination (Nätäänen et al., 1994; Nätäänen, 2001).

As for the Control group, they seemed to have a smaller MMN overall, that is on the right and on the left. This is interpreted as an indication of poorer sensitivity to the sound change in this contrast. This is not surprising considering that participants in this group did not receive any training and therefore no transfer of learning seems to have taken place.

Chapter 7 – General Discussion and Conclusions

7.1 Summary

7.1.1 Behavioural Experiments: Accuracy Rates and Reaction Times

One of the research questions addressed by this experiment is whether monolinguals, late bilinguals, early bilinguals and multilinguals differ with respect to their ability to discriminate a non-native contrast behaviourally before and after training. The question as to whether language learning experience has an impact on the ability to transfer the training received on a non-native contrast to the discrimination of another similar but different contrast was also investigated. Accuracy rate and reaction time on a training task (i.e. identification task) and a test of discrimination (i.e. AX task) were analysed in order to determine whether differences could be found between these groups.

The fact that previous research yielded inconclusive results with respect to the effect of language learning experience on discrimination abilities without training (Davine et al., 1971; Enomoto, 1994; Gallardo del Puerto, 2007; Rabinovitch & Parver, 1966; Werker, 1986) made it difficult to formulate hypotheses with respect to the results at Pre-Test. With respect to Post-Test, as was mentioned in Section 3.3, it was hypothesised that performance would get better as a function of the number of languages learned (i.e. monolinguals < bilinguals < multilinguals) based on the claim that more experienced language learners are better language learners (Herdina & Jessner, 2000). The differences were expected to be reflected by greater increases in accuracy rates and faster reaction times for more experienced language learners from Pre-Test to Post-Test. It was also hypothesised that the ability to transfer what is learned from training to a new but similar contrast would increase

as a function of the number of languages learned. Finally, it was also hypothesised that differences might be found at Post-Test and for the Test of Transfer based on the age of L2 acquisition for bilinguals.

With respect to accuracy rates, no significant group differences were found at Pre-Test suggesting that initial discrimination abilities do not differ based on language learning experience. These results are in agreement with those of Davine et al. (1971) and Werker (1986) who did not find any advantages for individuals with more language learning experience. The results are, however, in contradiction with those of Rabinovitch and Parver (1966) and Enomoto (1994) who did find that bilinguals and multilinguals were better than monolinguals at discriminating a non-native contrast. However, as was pointed out earlier, the fact that the method (e.g. task, stimuli, age and language background of the participants) employed differs greatly from one experiment to the next makes it difficult to make direct comparisons between the results of these experiments.

With respect to the effect of training, the results show that, overall, the participants were better at discriminating the non-native contrast at Post-Test compared to at Pre-Test. The results are in agreement with previous research that has shown that the ability to perceive sound differences in a non-native contrast can be recovered through training (Golestani & Zatorre, 2004; Kraus et al., 1995; Näätänen, 2001; Tremblay et al., 1997; Tremblay et al., 1998; Winkler, Kujala et al., 1999; Zhang & Wang, 2007). Nevertheless, the results of both the identification task and the AX discrimination task suggest that the rate at which individuals improve on these types of tasks over time appears to be influenced by language learning experience. With respect to the identification task, while no significant effect of

Group was found for any of the sessions, a significant effect of Session was found for both late bilinguals and multilinguals such that these two groups of participants improved significantly after only one training session. Monolinguals only showed improvement after two sessions and early bilinguals showed no significant improvement on the task from session to session. As for the AX task, the analysis revealed a significant effect of Group at Post-Test. The post-hoc analysis indicates that multilinguals were significantly more accurate than all of the other groups except for late bilinguals who were also more accurate than the control group. Moreover, when the accuracy rates at each test were compared for each group, multilinguals and late bilinguals were the only groups for which a significant effect of Test is found. Pairwise comparisons confirmed that their performance on the discrimination task improved significantly from Pre-Test to Post-Test suggesting that they benefited the most from training. Monolinguals and early bilinguals showed no improvement from Pre-Test to Post-Test. The results therefore suggest that while, initially, performance on a behavioural perception task (i.e. identification task and AX task) is similar regardless of the amount of language learning experience, multilinguals and, to some extent, late bilinguals, have superior learning abilities compared to monolinguals and early bilinguals. A more detailed discussion on the effect of the number of languages learned and the age of L2 acquisition can be found in Sections 7.3 and 7.4 respectively.

As for the Test of Transfer (AX task), no clear pattern was observed with respect to the effect of language learning experience on the accuracy rates. This therefore suggests that, at the behavioural level, the ability to transfer the training received on a non-native contrast to a new but similar contrast is not influenced by the amount of experience with learning languages. Perhaps such an influence would become apparent with more extensive training

and a more elaborated test of transfer of the type proposed by Pruitt et al. (2006), for instance.

As far as RTs are concerned, no group differences were found for any of the sessions for the identification task or for the various tests for the AX discrimination task. It can therefore be concluded that the amount of language learning experience does not affect the speed with which an individual is able to recognise a non-native sound or to discriminate a non-native contrast behaviourally.

7.1.2 Event-Related Potential Experiment

The experiment also sought to investigate whether language learning experience affects perceptual sensitivity at the neurophysiological level. More specifically, the issue under investigation concerned the potential differences across monolinguals, late bilinguals, early bilinguals and multilinguals in terms of the amplitude and typology of the MMN elicited by a non-native contrast before and after training. Moreover, potential MMN amplitude and typology differences for the transfer contrast across the various groups were also of interest in order to determine whether differences would be found in terms of transfer of learning.

As mentioned in Section 3.3, it was hypothesised that the electrophysiological discrimination of a non-native contrast would increase as a function of the number of languages learned (i.e. monolinguals < bilinguals < multilinguals) and would possibly differ based on the age of L2 acquisition for bilinguals. The effect of language learning experience was expected to be found both before and after participants were trained on the discrimination of the contrast as well as for the new but similar contrast after training. A

larger MMN amplitude was expected to be observed for more experienced learners at both testing times (i.e. Pre-Test and Post-Test). Moreover, differences in MMN typology were also expected to emerge among the groups. These hypotheses were based on previous research that has shown that discrimination at the neurophysiological level precedes discrimination at the behavioural level (Näätänen, 2001; Tremblay et al., 1998).

First of all, it is important to note that an MMN is observed for some groups for the non-native contrast before and after training. The results are in agreement with previous studies which have shown that an MMN can be elicited even by a non-native contrast, suggesting that the MMN can indicate both acoustic and phonemic sound discrimination (Dehaene-Lambertz, 1997; Maiste et al., 1995; Rivera-Gaxiola et al., 2000; Sharma & Dorman, 1999; Winkler, Kujala et al., 1999). Nevertheless, the results show that, at the neurophysiological level, language learning experience does affect the discrimination of a non-native contrast both initially and after training. Language learning experience also seems to have an impact on transfer of training.

At Pre-Test, the analysis revealed that the amplitude of the difference waves for late bilinguals was smaller than for the other groups. Moreover, while the pattern is especially true for the midline and, to some extent, the right electrode sites, other group differences were observed in the left electrode sites. The analysis revealed that, in the left electrode sites, multilinguals and, to some extent, early bilinguals had a larger MMN than the other groups. Similar results were obtained at Post-Test. Multilinguals seem to be most sensitive to the experimental contrast after training as well. This was evidenced by a larger overall MMN amplitude and by the fact that their MMN was bilateral rather than being mainly in

the midline and the right electrode sites. Early bilinguals also seemed to have a greater electrophysiological response to the sound change after training, at least compared to the control group. Moreover, like multilinguals, their MMN was more bilaterally distributed than the other groups. The fact that most group differences were observed in the midline and left electrode sites corroborate the results of an experiment by Shafer et al. (2004) which found similar typological differences between a group of Hindi and English speakers. The fact that monolinguals, late bilinguals and the control group seemed to have a midline and right lateralised MMN while multilinguals and, to a degree, early bilinguals had a more bilateral MMN suggests that language learning experience has an impact on the level of sensitivity to the non-native contrast even before getting trained on the discrimination of this contrast and certainly after. More experienced language learners, such as individuals who have learned at least three languages and who have learned two languages early on are more sensitive to sound changes that are not phonemic in their first language and possibly make use of additional resources in order to discriminate between these sounds. Moreover, differences in the amplitude of the difference waves on the left side could indicate differences in the level of activation in the left auditory cortex, which could in turn indicate differences in level of processing. It would be interesting to see if these claims could be confirmed if a similar study was conducted using fMRI technology. A more detailed discussion on the effect of the number of languages learned and the age of L2 acquisition can be found in Sections 7.3 and 7.4 respectively.

The changes in MMN amplitude from Pre-Test to Post-Test were also examined in order to confirm that training had an impact on the electrophysiological responses to the non-native contrast. The results indicated that, overall, the amplitude of the MMN was larger in the

midline and the right side electrodes at Post-Test. The results are in agreement with those of Tremblay et al. (1997) and Tremblay et al. (1998) which have shown that training can enhance the discrimination of a non-native contrast at the neurophysiological level.

Nevertheless, the results suggest once again that the effect of training was not the same for all groups. When groups were compared for MMN amplitude changes from Pre-Test to Post-Test, multilinguals and both groups of bilinguals stood out as most improved. The results of the analysis revealed that the increase in the amplitude of the MMN was greatest for multilinguals, followed by both groups of bilinguals. Combined with the results at Post-Test, the Pre-Test – Post-Test differences clearly demonstrate that the number of languages learned does have an impact on the extent to which an individual is able to learn to discriminate a non-native contrast as a result of training. It is clear that having learned three or more languages and, to some extent, having learned two languages, from birth or later, enhances the ability to develop an even greater level of sensitivity to sound differences that are not phonemic in the L1.

With respect to transfer of training, the results of the ERP experiment indicated that the various groups did not all discriminate the transfer contrast to the same extent. While monolinguals appeared to exhibit an MMN that was right lateralised, multilinguals and, to some extent, early and late bilinguals seemed to exhibit an MMN that was more bilateral or maybe even slightly left lateralised. It is interesting to note that this pattern is similar to what was observed at Pre-Test and Post-Test for the experimental contrast. The results therefore suggest that individuals who have learned only one language do not utilise the same neurological resources compared to individuals who have learned two or more languages when processing the transfer contrast. It can therefore be concluded that, at the

neurophysiological level, language learning experience has an impact on the ability to transfer what is learned on a contrast to the discrimination of another different but similar contrast.

7.2 Behavioural vs. Neurophysiological Discrimination

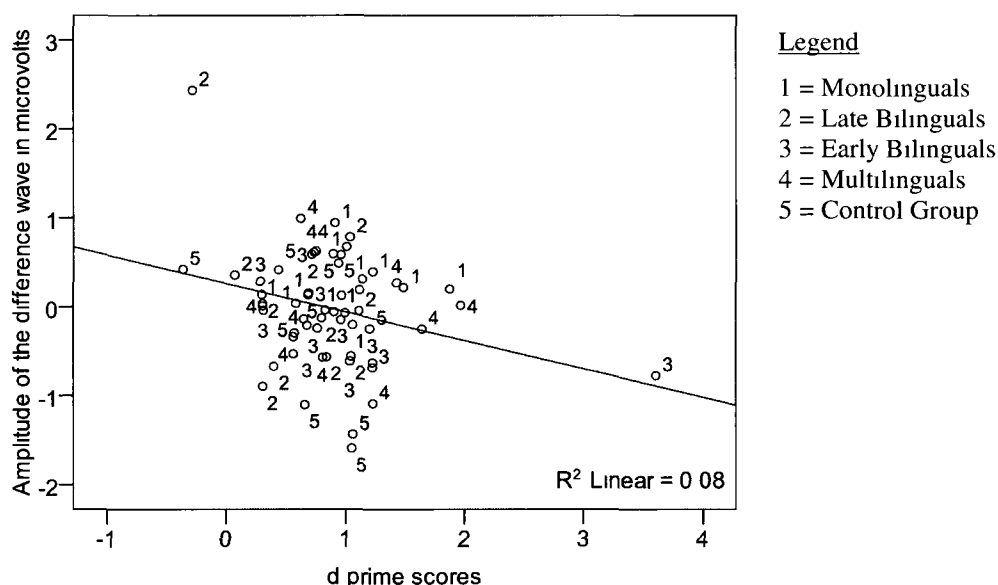
In this section, the differences and similarities between the results of the behavioural test of discrimination (i.e. AX task) and of the ERP experiment (i.e. MMN experiment) for the various tests will be discussed. Since RTs on the AX task do not seem to differ as a function of the amount of language learning experience, the following discussion on the relationship between speech perception at the behavioural and neurophysiological level will focus on accuracy rates only.

First of all, at Pre-Test, the analysis yielded different results for the behavioural task and the ERP experiment in terms of the effect of language learning experience on the initial discrimination abilities of the non-native contrast. On the one hand, the analysis revealed no significant effect of Group at the behavioural level suggesting that performance on a discrimination task did not differ based on whether an individual has learned one, two or three or more languages. At the neurophysiological level, on the other hand, differences were found among the groups. The amplitude of the difference wave for late bilinguals was smaller than the difference waves for the other groups, especially in the midline and, to some extent, the right electrode sites. Moreover, in the left electrode sites, multilinguals and, to some extent, early bilinguals had a larger MMN than the other groups. The fact that, at Pre-Test, differences were only found at the neurophysiological level without significant differences at the behavioural level is in agreement with previous research that has shown

that changes in electrophysiological discrimination may emerge before or without changes in the ability to discriminate a contrast behaviourally (Tremblay et al., 1998). Nevertheless, it is interesting to note that there is, to an extent, some correlation between the results of the discrimination task and the ERP experiment. Two-tailed Pearson correlations were performed on the d' scores and the average difference wave amplitude for each of the nine electrodes for each of the six time windows at Pre-Test. The analysis revealed a few significant or near significant correlations (F3 at 200-250ms: $r = -.225$, $p = 0.09$; FC3 at 200-250ms: $r = -.240$, $p = 0.069$; C3 at 200-250ms: $r = -.283$, $p = 0.031$; FC3 at 250-300ms: $r = -.262$, $p = 0.047$; C3 at 250-300ms: $r = -.269$, $p = 0.041$; C3 at 300-350 ms: $r = -.256$, $p = 0.053$). The negative correlation coefficients suggest that the d' scores increased as the amplitude of the difference waves increased by becoming more negative. Moreover, it is interesting to note that all of the significant (or nearly significant) correlations were found between the d' scores and the electrodes on the left side. Figure 7.1 illustrates the correlation found between the behavioural and the ERP data for C3 at 200-250ms. This suggests that enhanced discrimination abilities could be associated with a larger MMN amplitude on the left side. This is not surprising considering that enhanced neurophysiological discrimination is associated with a larger MMN amplitude in the left electrode sites (Dehaene-Lambertz et al., 2005; Näätänen et al., 1994; Näätänen, 2001). The results therefore suggest that behavioural and neurophysiological discrimination are, to some extent, correlated at Pre-Test. This is in agreement with previous research that also found a correlation between the two levels of discrimination (Dehaene-Lambertz et al., 2005; Lang et al., 1990; Näätänen, Paavilainen et al., 1993; Näätänen, Schröger et al., 1993; Sharma & Dorman, 1999; Tampas et al., 2005). Nevertheless, since no significant

group differences where found at Pre-Test at the behavioural level, the results confirm that the behavioural and the neurophysiological data provide different information with respect to initial discrimination abilities and that the latter provides a more precise measure of perceptual abilities.

Figure 7.1 – Correlation Between the Behavioural and the ERP Data for C3 at 200-250 ms

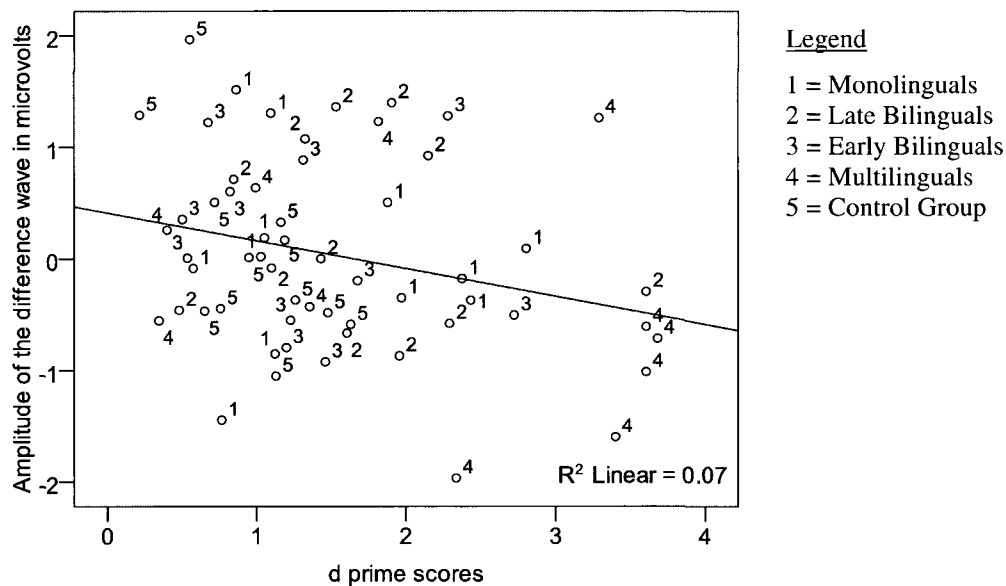


With respect to the discrimination of the experimental contrast at Post-Test, the results of both tests also provided different information about the effect of language learning experience on the ability to learn to discriminate a non-native contrast. At the behavioural level, the analysis revealed that multilinguals and, to some extent, late bilinguals are better learners. This is evidenced by the fact that their performance on the discrimination task improved significantly from Pre-Test to Post-Test. Some group differences were also found at the neurophysiological level. As was also the case at Pre-Test, multilinguals appear to be most sensitive to the experimental contrast after training. To some extent, early bilinguals

also seem to have a greater electrophysiological response to the sound change after training. It is clear that having learned three or more languages and, to some extent, having learned two languages from birth or later enhances speech perception. It is important to note, however, that the effect of having learned two languages seems to have a different impact on behavioural and neurophysiological discrimination depending on the age at which the L2 was learned. This issue is discussed in more details in Section 7.4.

Two-tailed Pearson correlation analyses were performed in order to determine whether a relationship could be found between the performance on the behavioural task and the neurophysiological responses at Post-Test. Several factors turned out to be significantly correlated or close to be significantly correlated (F3 at 150-200ms: $r = -.252$, $p = 0.057$; F3 at 200-250ms: $r = -.265$, $p = 0.044$; FC3 at 200-250ms: $r = -.219$, $p = 0.099$; F3 at 250-300ms: $r = -.343$, $p = 0.008$; FC3 at 250-300ms: $r = -.226$, $p = 0.088$; F3 at 300-350ms: $r = -.345$, $p = 0.008$; FC4 at 300-350ms: $r = -.228$, $p = 0.086$; F3 at 350-400ms: $r = -.306$, $p = 0.019$). The results indicate that, from 150ms on, behavioural discrimination is negatively correlated with neurophysiological discrimination, especially on the left. Figure 7.2 illustrates the correlation found between the behavioural and the ERP data for F3 at 200-250ms. The results are similar to those at Pre-Test and suggest that better behavioural discrimination abilities are associated with a larger MMN amplitude on the left. Once again, the results support the claim that behavioural and neurophysiological discrimination data really complement each other.

Figure 7.2 – Correlation Between the Behavioural and the ERP Data for F3 at 200-250 ms



Turning to the Test of Transfer, as was the case at Pre-Test, the results of the behavioural and neurophysiological tests yielded different results. While no significant group differences emerged from the behavioural discrimination task, the results of the ERP experiment indicate that the various groups do not all discriminate the transfer contrast at the neurophysiological level to the same degree. The right lateralised MMN for monolinguals compared to the bilateral or maybe even slightly left lateralised MMN for multilinguals and, to some extent, early and late bilinguals, indicate that individuals who have learned only one language use different neurological resources compared to individuals who have learned two or more languages when processing the transfer contrast. It can therefore be concluded that, while behavioural discrimination abilities do not differ significantly, the neurophysiological data suggest that language learning experiment does have an impact on the ability to transfer what is learned on a contrast to the discrimination of another different but similar contrast.

To summarise the results of the experiments, while group differences at the behavioural level are only apparent at Post-Test, at the neurophysiological level, language learning experience affects perceptual sensitivity to the non-native contrast before and after training. Moreover, although the effect is only observed at the neurophysiological level, language learning experience seems to affect the ability to transfer what is learned to a different but similar contrast as well.

7.3 Monolinguals vs. Bilinguals vs. Multilinguals

The results of both the behavioural and the ERP experiments confirm that the amount of experience in learning languages does have an impact on speech perception. The effect is not only noticeable in terms of initial abilities to discriminate a non-native contrast, but also with respect to the degree to which an individual is able to learn to better discriminate this contrast and to apply what has been learned in order to discriminate a new but similar contrast. It is important to mention that the effect of language learning experience is apparent even as a result of having learned only one additional language. The results clearly indicate that bilinguals, whether they have learned their L2 in the first year of life or later, exhibit certain advantages over monolinguals in terms of perceptual sensitivity to non-phonemic sound differences.

It is also important to note that a noticeable difference is also observed between bilinguals and individuals who have learned three or more languages. In both experiments, multilinguals definitely show signs of superior perceptual sensitivity to the non-phonemic sound difference compared to all of the other groups. Based on the results, it is possible to conclude that initial perceptual sensitivity to non-phonemic sound differences as well as

learning abilities increase from one to two languages and from two to three or more languages. While the results of these experiments do not address this issue, it would be interesting to see whether perceptual sensitivity continues to increase in the same way beyond three languages such that a significant difference would be noticed between three and four languages and so on.

Alternatively, it could be argued that bilinguals and multilinguals were better than monolinguals because they know French, which has a dental stop as in the dental/retroflex contrast. This interpretation of the results can however be safely rejected based on the fact that native speakers of French also have difficulty discriminating the dental/retroflex contrast (Dehaene-Lambertz, 1997). It would nevertheless be interesting to test this claim by replicating the experiment with individuals who have learned an L2 that has neither a dental nor a retroflex sound in their phonemic inventory. In fact, it will be important to replicate this experiment with a variety of different combinations of languages and on the discrimination of different types of contrasts (e.g. vowel contrasts, consonantal contrasts related to voicing, manner or place of articulation). This will make it possible to confirm whether or not the better performance of bilinguals and multilinguals compared to monolinguals was indeed due to their language learning experience rather than to their knowledge of specific languages. Furthermore, such studies should also make it possible to determine whether the degree of similarity between the various languages learned by bilinguals and multilinguals has an impact on the extent to which perceptual sensitivity is enhanced by language learning experience and whether it applies to different types of contrasts across the board.

7.4 Early Bilinguals vs. Late bilinguals

While the experiment was not specifically designed to investigate thoroughly how the age at which an L2 is acquired affects speech perception and learning abilities, it was nevertheless important to consider the type of bilingualism (early and late) separately. Studies have shown that the age of L2 acquisition has an impact on language processing in other areas such as lexical and morpho-syntactic processing (Stowe & Sabourin, 2005). It appears that differences are also found between early and late bilinguals in terms of the way sounds are processed. At the behavioural level, late bilinguals demonstrate a greater improvement in terms of discriminating the non-native contrast after training than early bilinguals. It should be noted, however, that the fact that late bilinguals improve significantly from Pre-Test to Post-Test while early bilinguals do not could simply be due to the fact that early bilinguals were better at Pre-Test to begin with and there was less room for improvement. At the level of electrophysiological discrimination, on the other hand, early bilinguals show greater sensitivity to the non-native contrast both initially and after training compared to late bilinguals. It is important to note, however, that both groups are fairly similar with respect to the MMN amplitude increase from Pre-Test to Post-Test. The results therefore suggest that while having learned two languages enhances perceptual sensitivity and learning abilities compared to having learned only one language, the age of acquisition of the L2 also has an impact. While having learned two languages from birth might contribute to greater perceptual sensitivity at the neurophysiological level, having had the experience of learning an L2 at a later age might contribute to an increased ability to learn to discriminate a non-native contrast behaviourally.

This interpretation of the results seems logical when we consider that the two types of acquisition differ in terms of the level of consciousness with which the L2 was likely learned. On the one hand, learning an L2 at a later age may require a greater level of consciousness on the part of the learner simply because the individual is more likely to be aware of the differences between the L1 and the L2. Furthermore, late bilinguals in this experiment mostly learned their L2 in a formal setting, a setting in which differences in terms of the phonological system of the L1 and the L2 were likely explicitly brought to their attention. The skills acquired by late bilinguals as a result of L2 learning are probably more readily transferable to a task such as the one involved in the behavioural experiments (testing and training) and this is probably why bilinguals outperformed early bilinguals behaviourally. If the age and the context of acquisition in which late bilinguals learned their L2 help them with sound discrimination at a more conscious level, it is not surprising that the pattern of electrophysiological responses was different from that of the other groups. As mentioned earlier, it would be interesting to see whether, instead of exhibiting an MMN, late bilinguals exhibit a P300 as this ERP component has been associated with a more conscious level of discrimination.

Conversely, early bilinguals learned two languages naturally, by simple exposure to the languages in their environment. The fact that they were so young when they learned French and that they did not receive formal instruction in this language (i.e. they were not necessarily explicitly taught about differences between the two languages) may in turn help them with sound discrimination at a pre-attentive level and not necessarily at a more conscious level. This would explain why they show enhanced perceptual sensitivity at the neurophysiological level, but not at the behavioural level.

While this issue should be further investigated in order to understand more fully the role that age of L2 acquisition plays in shaping speech perception, the results certainly suggest that both the number of languages and the age at which an L2 is learned influence speech perception. It should also be mentioned that, within the multilingual group, some have learned their first two languages simultaneously while others are late bilinguals who went on to learn additional languages. While the number of participants does not make it possible to investigate this issue, it would be interesting to see whether differences are observed among multilinguals based on the age at which their L2 was learned. Future studies should therefore investigate whether multilinguals who are late bilinguals are more similar to late bilinguals and multilinguals who are early bilinguals are more like early bilinguals in terms of behavioural and neurophysiological discrimination.

7.5 Level of Processing

Speech processing is thought to be mediated by our L1 phonological system which filters out acoustic information that is not important to the understanding of what is said. This filter makes it difficult to perceive sound differences that are not phonemic. In order to be able to perceive non-phonemic differences, it may therefore be necessary, to some extent, to turn off the phonetic/phonemic sound analysis system and rely more on the acoustic sound analysis system. Since multilinguals and, to some extent, bilinguals are better at discriminating the non-native contrasts, it could be argued that, thanks to their language learning experience, more experienced language learners are able to do so. In other words, more experienced learners might be better at processing sounds at a more acoustic level rather than at a phonetic/phonemic level.

As was mentioned in the review of the literature, speculations can be made about the level at which sound differences are processed (i.e. acoustic vs. phonetic) based on the typology of the MMN. Some have argued that a right lateralised or bilateral MMN is indicative of acoustic processing and a left lateralised MMN is characteristic of phonetic processing (Näätänen, 2001; Tremblay et al., 1997). Greater activation in the left electrode sites has been associated with the processing of sounds linguistically as well as acoustically (as opposed to simply acoustically). The linguistic analysis of sounds is potentially mediated by some abstract phonetic or even phonemic representations in the left auditory cortex (Golestani & Zatorre, 2004; Näätänen et al., 1997). The results of the ERP experiment for the experimental contrast indicate that multilinguals and, to some extent, early bilinguals have a more bilateral MMN while monolinguals and late bilinguals seem to have a more midline and right lateralised MMN. While the MMN is not left lateralised for any of the groups, the larger MMN on the left for multilinguals and, to some degree, early bilinguals compared to the other groups can nevertheless be interpreted as a sign of greater left side activation. As mentioned earlier, greater left side activation is associated with the processing of speech sounds (Shafer et al., 2004). The results therefore suggest that, compared to monolinguals, multilinguals and, to a certain extent, bilinguals activate brain regions which are associated with the processing of linguistically relevant acoustic information even when processing a non-native contrast. In other words, multilinguals and, to a certain extent, bilinguals process the difference between the dental and the retroflex not just acoustically, but possibly phonetically as well.

Arguing that more experienced learners are better at processing sounds at a more acoustic level may seem, at first sight, contradictory with arguing that the greater left side activation

is due to them processing the sounds linguistically. However, the two arguments can be reconciled if the processing of a non-native contrast is broken down in different steps. The first step in being able to perceive the difference between a pair of sounds in a non-native contrast is being able to analyse them acoustically, not allowing the L1 phonological system to categorise the sounds systematically. If enough acoustic differences are perceived between the two sounds, then a representation can be created for the new sound (in this case the retroflex could be the new sound as the dental is probably processed at the alveolar category already established in the L1 system of the participants). This representation can then be used by the speech sound analysis system the next time the sound is heard.

Applying this to the data, it could be argued that, because they are able to process sounds at a more acoustic level, more experienced learners are able to perceive the difference between the two sounds in the non-native contrast. Then, as a result of being exposed to the stimuli during the testing phase and thanks to training, they are able to create a representation for the new sound which, in turn, is used to discriminate the contrast. The fact that the contrast is discriminated based on actual representations (as opposed to being processed only acoustically) could explain the greater left side activation for more experienced learners.

Although the results do not make it possible to draw any clear conclusions regarding the effect of language learning experience on the level of processing of acoustic details in a non-native contrast, the differences observed between the groups do imply that more experienced language learners exhibit increased sensitivity to the non-native contrast.

Whether the greater activation on the left observed for multilinguals and bilinguals is due to the use additional resources (potentially 'permanent'/phonetic memory traces which have

been formed as a result of training) or due to different levels of activation of the same resources is not clear. It would be interesting to see whether clearer group differences in terms of MMN typology would emerge at Post-Test if the experiment involved a more extensive training period. Potentially, the group difference in terms of left side activation would become more marked as the MMN would eventually become more left lateralised for more experienced learners. A similar experiment relying on fMRI technology could also help answer this question.

With respect to the behavioural experiment, the design of the AX task does not make it possible to speculate about possible effects of language learning experience on the level of processing. Some argue that a shorter ISI tests acoustic discrimination and a longer ISI tests phonetic or phonemic discrimination (Werker & Logan, 1985). Set at 1000ms, the ISI of the AX task was meant to test phonetic or even perhaps phonemic discrimination rather than acoustic discrimination. It would therefore also be interesting to see whether similar group differences would emerge if a shorter or longer ISI was used. In other words, it would be interesting to see whether similar effects of language learning experience are observed at a purely acoustic and a purely phonemic level of processing.

7.6 Learning Abilities and Brain Plasticity

As was just mentioned in the previous sections, the ability to learn to discriminate a non-native contrast differs as a function of the number of languages learned and possibly the age of acquisition of these languages. This conclusion was drawn based on the fact that greater increases in MMN amplitude and behavioural discrimination abilities were observed for multilinguals and bilinguals compared to monolinguals. From a perspective of

brain plasticity, the results suggest that having learned more than one language contributes to the maintenance of greater neurophysiological plasticity. It has been argued that while non-native contrasts can be discriminated acoustically, native contrasts are thought to be processed both acoustically and phonetically based on memory traces stored in the left auditory cortex (Näätänen et al., 1997; Näätänen, 2001). This double activation is thought to be what causes an MMN resulting from the discrimination of a native contrast to have a greater amplitude compared to an MMN resulting for the discrimination of a non-native contrast. Based on these claims, it can be argued that the greater changes in the MMN for multilinguals and bilinguals after training may be indicative of an enhanced ability to create memory traces for new sounds. The memory traces created through training are then used to process the new sounds. In turn, this translates into an increase in MMN amplitude as well as superior behavioural discrimination abilities.

At this point, it is only possible to speculate on this issue since the Pre-Test – Post-Test differences only seem to involve changes in amplitude. Again, stronger claims could be made if differences among monolinguals, bilinguals and multilinguals were also to be observed in terms of changes in the typology of the MMN after training. It would therefore be interesting to see whether such differences would emerge out of an experiment involving a more extensive period of training. For instance, if a shift from a right lateralised or bilateral MMN to a left lateralised MMN was observed after training for multilinguals and bilinguals, it could be claimed with more certainty that more extensive language learning experience helps maintain a higher level of brain plasticity.

7.7 Implications for the Field of First Language Acquisition

When comparing the data for the monolinguals and the early bilinguals, the results of the experiment can inform us about L1 acquisition in different linguistic environments. The results indicate that, compared to monolingual acquisition, bilingual L1 acquisition leads to greater perceptual sensitivity to the acoustic details in sounds such that the individual can more easily discriminate a non-phonemic contrast at the neurophysiological level. This is evidenced by a larger difference wave amplitude at Pre-Test on the left for early bilinguals. Having learned two languages from birth also appears to help develop greater learning abilities. This claim is supported by the fact that early bilinguals also showed greater changes in the amplitude of the difference wave from Pre-Test to Post-Test compared to monolinguals. Since learning to discriminate a new phonetic contrast requires the creation of new memory traces, and since the creation of new memory traces requires greater brain plasticity, the results suggest that learning two languages from birth helps maintain a higher level of brain plasticity.

7.8 Implication for the Field of Second Language Acquisition

Although they differ in the exact claims they make, models of L2 speech perception (e.g. Speech Learning Model, Flege, 1995, Perceptual Assimilation Model, Best, 1995) share the idea that speech sound processing is mediated by the way sounds are analysed by our L1 phonological system. For instance, when two sounds in a non-native contrast are perceived as belonging to the same category in our L1 system, it is difficult to perceive the difference between them.

The results of the experiment can be applied to such models of L2 speech processing in an attempt to illustrate how language learning experience might be affecting the processing of non-native contrasts. On the one hand, it could be hypothesised that monolinguals exhibit greater difficulty discriminating the contrast because they assimilate the dental and the retroflex stop to the same category (possibly the alveolar stop category). On the other hand, it could be hypothesised that multilinguals and bilinguals are more able to perceive the difference between the two sounds because they do not assimilate them to the same category. This is directly related to the issue of level of processing addressed earlier. Multilinguals and bilinguals possibly do not assimilate the two sounds to the same category because they are more able to analyse them acoustically, with less interference from their L1 phonological system. In turn, because they are able to perceive the acoustic details of the sounds more accurately, they are potentially able to create memory traces or some kind of representation for new sounds that are distinct from any of the L1 categories already established. They can then refer to the new categories/representations in order to process sounds and discriminate non-native contrasts containing these sounds. The data supports this claim since the amplitude of the difference wave recorded in the left electrode sites is greater for multilinguals and bilinguals compared to monolinguals. Some have argued that phonetic processing of speech sound is characterised by an increased level of activation in the left compared to purely acoustic processing of sounds.

7.9 Methods for Studying Speech Processing

When comparing the results of the AX discrimination task and of the ERP experiment (MMN) for the various tests, it is clear that the two methods do not yield the same results

and seem to complement each other. If the research questions had been investigated by relying solely on a behavioural discrimination task, it would have been impossible to establish that the number of languages learned also influences initial discrimination abilities and the ability to transfer training to a new contrast. This experiment demonstrates that neurophysiological methods are a more insightful way to test speech perception as they are more sensitive to more subtle differences. The results at both levels therefore show that both methods should be combined in order to obtain a more complete picture of how language learning experience shapes speech perception.

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Appendix 1 – Recruitment Questionnaire

Please write the last letter of your name followed by the last four digits of your phone number: _____

Age: _____ Gender: ☐ Male ☐ Female ☐ right-handed ☐ left-handed ☐ ambidextrous

- What is your native language (the 1st language you have learned from birth)? _____
 - o Do you still speak this language natively? ☐ yes ☐ no
 - if no, specify level of proficiency: _____
- What is the 2nd language you learned/studied? _____
 - o Age of 1st exposure: _____ Context of acquisition: _____
 - o Level of proficiency: _____
- What is the 3rd language you learned/studied? _____
 - o Age of 1st exposure: _____ Context of acquisition: _____
 - o Level of proficiency: _____
- What is the 4th language you learned/studied? _____
 - o Age of 1st exposure: _____ Context of acquisition: _____
 - o Level of proficiency: _____
- What is the 5th language you learned/studied? _____
 - o Age of 1st exposure: _____ Context of acquisition: _____
 - o Level of proficiency: _____
- What is the 6th language you learned/studied? _____
 - o Age of 1st exposure: _____ Context of acquisition: _____
 - o Level of proficiency: _____
- Have you learned or studied other languages? ☐ yes ☐ no
 - o If yes, please indicate which language(s) (please indicate all languages, even those you have very little knowledge of) and your level of proficiency.

- Please indicate which language(s) you usually speak in the following contexts.
 - o If you speak more than one language in one context, list them from most frequent to least frequent and indicate roughly the percentage of use for each language.

<u>Context</u>	<u>Language</u>
<i>e.g.</i> With friends	English (75%) French (25%)
With my family	_____
With friends	_____
At school	_____
At work	_____
Other (specify: _____)	_____
Other (specify: _____)	_____

Based on your answers on this questionnaire, you might be selected to participate in an experiment about language acquisition. If you are interested in participating in this study, please provide your email address and/or a phone number where you can be reached. Please note that participating in this questionnaire is voluntary and does not guarantee that you will be selected to participate in the study. You will be contacted by the researcher in order to be informed of the outcome of the selection process.

Email address: _____ Phone number: _____

Appendix 2 – Background Questionnaire

Participant number: _____

Age: _____

Gender: ☐ Male ☐ Female

- What is/are your native language(s) (the 1st language(s) you have learned from birth)?
 - (1) _____ (2) _____ (3) _____
 - Do you still speak this/these language(s) natively? ☐ yes ☐ no
 - If no, specify which language and your level of proficiency:
 - Language: _____
 - Level of oral proficiency: ☐ very low ☐ low ☐ intermediate ☐ near-native ☐ native
 - Level of written proficiency: ☐ very low ☐ low ☐ intermediate ☐ near-native ☐ native
 - Comments on proficiency: _____
 - Language: _____
 - Level of oral proficiency: ☐ low ☐ intermediate ☐ near-native ☐ native
 - Level of written proficiency: ☐ low ☐ intermediate ☐ near-native ☐ native
 - Comments on proficiency: _____
- What is the 2nd language you learned/studied? _____
 - Age of 1st exposure: _____
 - Level of oral proficiency: ☐ very low ☐ low ☐ intermediate ☐ near-native ☐ native
 - Level of written proficiency: ☐ very low ☐ low ☐ intermediate ☐ near-native ☐ native
 - Comments on proficiency: _____
- What is the 3rd language you learned/studied? _____
 - Age of 1st exposure: _____
 - Level of oral proficiency: ☐ very low ☐ low ☐ intermediate ☐ near-native ☐ native
 - Level of written proficiency: ☐ very low ☐ low ☐ intermediate ☐ near-native ☐ native
 - Comments on proficiency: _____
- What is the 4th language you learned/studied? _____
 - Age of 1st exposure: _____
 - Level of oral proficiency: ☐ very low ☐ low ☐ intermediate ☐ near-native ☐ native
 - Level of written proficiency: ☐ very low ☐ low ☐ intermediate ☐ near-native ☐ native
 - Comments on proficiency: _____
- What is the 5th language you learned/studied? _____
 - Age of 1st exposure: _____
 - Level of oral proficiency: ☐ very low ☐ low ☐ intermediate ☐ near-native ☐ native
 - Level of written proficiency: ☐ very low ☐ low ☐ intermediate ☐ near-native ☐ native
 - Comments on proficiency: _____
- Have you learned or studied other languages? ☐ yes ☐ no
 - If yes, please indicate which language(s) (please indicate all languages, even those you have very little knowledge of) and your level of proficiency.

Appendix 2 – Background Questionnaire

- Please indicate which language(s) you speak on the following contexts and the percentage of use for each language if more than one language apply to the same context.
 - o Note: If you speak more than one language in one context, your answer must add up to 100% of the time.

	Language(s) (%)
<i>Example: with friends</i>	<i>English (75%); French (20%); German (5%)</i>
☐ with your mother	_____
☐ with your father	_____
☐ with your siblings	_____
☐ with your extended family	_____
☐ with your partner	_____
☐ with friends	_____
☐ at school	_____
☐ At work	_____
☐ At the grocery store	_____
☐ When watching TV	_____
☐ When reading the newspaper	_____
☐ When reading for pleasure	_____
☐ When travelling (How often?)	_____
☐ Other context (specify):_____	_____
☐ Other context (specify):_____	_____
☐ Other context (specify):_____	_____

Appendix 2 – Background Questionnaire

Context of Language Acquisition

Please indicate which language(s) you have learned in the following context by writing the number of months, semesters or years you have been learning them in the appropriate squares. Also indicate the dates (e.g. from: 1990 to: 2000). Please let the researcher know if you need additional columns.

Language Context							
Home							
Nursery/ kindergarden							
Elementary school							
High school							
College							
University							
Language school							
Other: (specify)							

Comments:

General Information

What is your current occupation? _____

What is the last level of education that you obtained (or that you are currently working on)?

Appendix 2 – Background Questionnaire

Handedness

Please indicate which hand you usually use for the following activities (i.e. right, left or both). Try visualizing yourself performing the activity. If you are not entirely sure which hand you use, please indicate that you use both hands.

	right	left	both hands
Which hand do you use to hold a toothbrush when cleaning teeth?	☐	☐	☐
With which hand do you use a bottle opener?	☐	☐	☐
With which hand do you throw a ball away?	☐	☐	☐
Which hand do you use to hold a hammer?	☐	☐	☐
With which hand do you hold a racket when playing tennis?	☐	☐	☐
With which hand do you cut a cord with a knife?	☐	☐	☐
With which hand do you stir with a spoon?	☐	☐	☐
With which hand do you use an eraser on paper?	☐	☐	☐
With which hand do you strike a match?	☐	☐	☐

Which hand do you usually write with?

☐ right ☐ left ☐ both hands

Do you remember being forced to write with that hand even though it felt awkward?

☐ yes ☐ no

Hearing Screening

	500 Hz	1000 Hz	2000 Hz	4000 Hz
Right ear (in dB HL)				
Left ear (in dB HL)				

Appendix 3 – Participants Information

CONTROL GROUP													
Participant Number	Participation		Age	Gender	L1			L2			Other languages ¹		
	Behavioural	ERP			Language	AoA ²	Proficiency	Language	AoA	Proficiency	Language	AoA	Proficiency
C001	x	x	22	f	English	0	native	French	9	low-intermediate			
C002	x	x	24	f	English	0	native	French	6	intermediate			
C003	x	x	31	m	English	0	native	French	5	intermediate			
C004	x	x	22	f	English	0	native	French	4	low-intermediate			
C005	x	x	20	f	English	0	native	French	8	intermediate			
C006	x	x	19	m	English	0	native	French	6	low			
C007	x	x	18	m	English	0	native	French	7	low			
C008		x	19	f	English	0	native	French	0	low-intermediate			
C009	x	x	18	f	English	0	native	French	0	intermediate-advanced	Japanese	14	intermediate
C010	x	x	18	f	English	0	native	French	5	very low			
C011	x	x	21	f	English	0	native	French	6	very low			
C012	x	x	36	f	English	0	native	French	12	low-intermediate			
C013	x	x	20	f	English	0	native	French	4	low			

¹ Only languages in which proficiency was assessed as being at least intermediate are included.

² AoA: Age of Acquisition

Appendix 3 – Participants Information

MONOLINGUALS										
Participant Number	Participation		Age	Gender	L1			L2		
	Behavioural	ERP			Language	AoA	Proficiency	Language	AoA	Proficiency
E003	x	x	20	f	English	0	native	French	10	very low
E004	x		22	f	English	0	native	French	4	low
E005	x	x	21	f	English	0	native	French	5	low-intermediate
E018	x	x	24	f	English	0	native	French	9	low
E028	x	x	23	f	English	0	native	French	7	very low
E031	x	x	28	m	English	0	native	French	25	low
E032	x	x	23	f	English	0	native	French	6	very low
E034	x	x	34	f	English	0	native	French	7	very low
E035	x	x	20	m	English	0	native	French	17	low
E038	x	x	27	m	English	0	native	French	3	very low
E039	x	x	23	m	English	0	native	French	4	low
E041	x	x	26	f	English	0	native	French	10	low
E048	x	x	19	f	English	0	native	French	6	very low

Appendix 3 – Participants Information

LATE BILINGUALS										
Participant Number	Participation		Age	Gender	L1			L2		
	Behavioural	ERP			Language	AoA	Proficiency	Language	AoA ³	Proficiency
E001	x	x	18	f	English	0	native	French	5	near native
E008	x	x	19	f	English	0	native	French	4	intermediate
E010	x	x	21	f	English	0	native	French	5	intermediate-advanced
E013	x	x	20	f	English	0	native	French	4	intermediate-advanced
E015	x	x	25	f	English	0	native	French	3	intermediate
E016	x	x	19	f	English	0	native	French	6	intermediate-advanced
E019	x	x	20	f	English	0	native	French	10	near native
E021	x	x	28	f	English	0	native	French	4	near native-advanced
E042	x	x	28	f	English	0	native	French	6	advanced
E049	x	x	18	f	English	0	native	French	4	near native
E050	x	x	21	f	English	0	native	French	5	intermediate-advanced
E052	x	x	21	f	English	0	native	French	5	advanced

³ All of them started to learn French in a formal setting (e.g. kindergarten, elementary school) and none of them were exposed to French at home.

Appendix 3 – Participants Information

EARLY BILINGUALS										
Participant Number	Participation		Age	Gender	L1					
	Behavioural	ERP			Language	AoA	Proficiency	Language	AoA ⁴	Proficiency
E002	x		20	f	English	0	native	French	0	native
E007	x	x	21	f	English	0	native	French	0	near native
E011	x	x	21	m	English	0	native	French	0	native
E012	x	x	21	m	English	0	native	French	0	native
E017	x	x	22	f	English	0	native	French	0	native
E020	x	x	20	f	English	0	native	French	0	native
E022	x	x	18	f	English	0	native	French	0	native
E023	x	x	29	m	English	0	native	French	0	advanced
E024	x	x	21	f	English	0	native	French	0	advanced
E026 ⁵	x		24	m	English	0	native	French	0	native
E027	x	x	31	m	English	0	native	French	0	native
E036	x	x	22	f	English	0	native	French	2	near-native
E037		x	19	m	English	0	native	French	0	native
E043	x	x	18	f	English	0	native	French	0	native

⁴ All of them were exposed to French at home, except for E036 who started to be exposed to French in a bilingual programme in preschool.

⁵ Participant E026 is left handed and therefore only participated in the behavioural experiment.

Appendix 3 – Participants Information

MULTILINGUALS													
Participant Number	Participation		Age	Gender	L1			L2			Other languages		
	Behavioural	ERP			Language	AoA	Proficiency	Language	AoA	Proficiency	Language(s)	AoA	Proficiency
E009	x	x	29	m	English	0	native	French	4	near native	Spanish	16	advanced-intermediate
E014	x		30	m	English	0	native	French	15	near native	Spanish Japanese Mandarin	13 22 28	intermediate intermediate intermediate
E025	x	x	18	f	English French	0	native				Spanish	16	intermediate
E029	x	x	33	f	English	0	native	French	3	near native	Japanese	18	intermediate
E033	x	x	21	f	English	0	native	French	4	advanced-intermediate	Spanish	16	intermediate
E040	x	x	27	f	English	0	native	French	5	near native	Spanish	17	near native
E044	x	x	19	f	English	0	native	French	4	near native	Vietnamese	19	intermediate
E045	x	x	20	f	English	0	native	French	3	near native	Spanish	17	intermediate
E046	x	x	18	m	English French	0	native	French	5	native	Spanish	15	near native
E047	x	x	18	f	English French Italian	0	native						
E051	x	x	21	f	English French	0	native				Spanish	17	advanced
E053	x	x	39	m	English	0	native	French	0	near native	German Spanish	7 14	advanced intermediate

Voiceless Aspirated Dental and Retroflex Stops					
Token	Duration	VOT	Token	Duration	VOT
dental 1	315 ms	82 ms	retroflex 1	316 ms	76 ms
dental 2	324 ms	82 ms	retroflex 4	304 ms	89 ms
dental 3	322 ms	59 ms	retroflex 2	294 ms	67 ms
dental 4	356 ms	82 ms	retroflex 3	292 ms	75 ms
<i>mean</i>	<i>329.25 ms</i>	<i>76.25 ms</i>	<i>mean</i>	<i>302.5 ms</i>	<i>76.75</i>
<i>range</i>	<i>315-356 ms</i>	<i>59-82 ms</i>	<i>range</i>	<i>292-316 ms</i>	<i>67-89 ms</i>

Voiceless Unaspirated Dental and Retroflex Stops					
Token	Duration	VOT	Token	Duration	VOT
dental 1	270 ms	13 ms	retroflex 1	264 ms	75 ms
dental 2	264ms	10 ms	retroflex 2	266 ms	89 ms
dental 3	287 ms	8 ms	retroflex 3	245 ms	76 ms
dental 4	284 ms	16 ms	retroflex 4	308 ms	67 ms
<i>mean</i>	<i>276.25 ms</i>	<i>11.75 ms</i>	<i>mean</i>	<i>270.75 ms</i>	<i>5.75</i>
<i>range</i>	<i>264-287 ms</i>	<i>8-16 ms</i>	<i>range</i>	<i>245-308 ms</i>	<i>67-89 ms</i>

Voiceless Aspirated Labial and Velar Stops					
Token	Duration	VOT	Token	Duration	VOT
labial 1	451 ms	95 ms	velar 1	414 ms	81 ms
labial 2	445 ms	91 ms	velar 2	420 ms	78 ms
<i>mean</i>	<i>448 ms</i>	<i>93 ms</i>	<i>mean</i>	<i>417 ms</i>	<i>79.5</i>



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Faculté des arts
Linguistique
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Faculty of Arts
Linguistics

Consent Form

Study on the Perception of Phonemic Contrasts

Researcher	Marie-Claude Tremblay, Ph.D. candidate Department of Linguistics, University of Ottawa Office: 60 University Street, room 333E, Ottawa, ON K1N 6N5 Phone: (613) 562-5800 ext. 1125 Email: mtrem075@uottawa.ca	
Supervisors	Professor Ian MacKay Department of Linguistics, University of Ottawa 70 Laurier Ave, room 447 Ottawa, ON K1N 6N5 Phone: (613) 562-5800 ext 1753 Email imackay@uottawa.ca	Professor Laura Sabourin Department of Linguistics, University of Ottawa 70 Laurier Ave, room 439 Ottawa, ON K1N 6N5 Phone: (613) 562-5800 ext 1763 Email: laura.sabourin@uottawa.ca

Invitation to participate: I am invited to participate in a study conducted by Marie-Claude Tremblay, Ph.D. student in the department of linguistics, and supervised by Professor Ian MacKay and Laura Sabourin.

Purpose of the study: The purpose of the study is to investigate the perception of speech sounds by individuals who have different language learning background. The study will look at the extent to way my brain responds to changes in auditory stimuli (sounds) and my ability to actively identify these changes..

Participation: The experiment will spread over three separate sessions and will include the following components. During the first session, I will first be asked to fill out a questionnaire about my language learning background. Then, I will take part in a three-part experiment. First, I will take part in an event-related potential (ERP) experiment (Part 1), during which I will simply be presented with stimuli through headphones while wearing a helmet with electrodes hooked to a computer that will record the neurophysiological activity. Then, I will take part in a behavioural experiment (Part 2), during which I will be presented with pairs of sounds through headphones and be asked to indicate whether I perceive the two sounds as the 'same' or as 'different'. Following the behavioural test, I will participate in a training session (Part 3). During this phase, I will be trained to discriminate between the two sounds presented during the first two parts of the experiment. I will be presented with pairs of sounds through headphones and be asked to indicate whether I perceived the two sounds as the 'same' or 'different' in the same I did during the discrimination task only this time I will be given feedback on my answers. During the second session, which will take place 4-5 days later, I will repeat Part 3. Finally, during the third session, which will take place 4-5 days later, Part 3, 1 and 2 will be repeated.

In order to record my brain waves (ERP experiment), I will be asked to wear an elastic cap with small electrodes attached to it. The cap fits tightly, but not uncomfortably, on my head. Additional electrodes will be placed around my eyes, behind my ears and on my nose. These will be attached using paper tape. My skin may be rubbed gently with rubbing alcohol. I understand that the placement of these electrodes on my head is not painful, although there may be minor discomfort when my skin is rubbed. I am also aware that the skin may be slightly

reddened after the electrodes are removed. This reddening will disappear within a few hours. All electrodes will be filled with gel. This is easily removed later by washing the skin and hair. I understand that I will be asked to refrain from moving and blinking as much as possible during the testing

Risks: There are no real risks associated with this study. Nevertheless, since the experiment will last over several hours (approximate during times: session 1: 3 hours, session 2: 1 hour; session 3: 3 hours), it is possible that I will feel tired. If this happens, I will have the possibility to interrupt the experiment to take a break.

Confidentiality and anonymity: The information I will provide will remain strictly confidential. Anonymity will be ensured through the use of codes instead of names. My name or any information that could identify me will not be released to anyone or in any publication. If quoting individual excerpts, anonymity will be ensured through the use of codes in order to refer to these individuals. The data will be used only for the abovementioned study

Conservation of data: The data collected, namely the questionnaire, the EEG recordings and the answer on the behavioural test, will be conserved for a period of 25 years. The paper version of the questionnaire as well as the EEG and behavioural data (copied onto CDs) will be kept in a secure place in the researcher's office in the Department of Linguistics at the University of Ottawa. Only the research and her supervisor will have access to the data. In addition to being used for the present study, there is also a possibility that the data collected will be used for future research.

Voluntary participation: My participation is voluntary and I have the right to decide not to participate or to withdraw from this study at any time without negative consequences. If I decide to withdraw from the study, all information related to me will be erased and completely removed from the study.

Acceptance: I, _____, agree to participate in this study conducted by Marie-Claude Tremblay under the supervision of Professor Ian MacKay and Laura Sabourin.

If you have questions concerning the study, please contact Marie-Claude Tremblay or her supervisors. If you have any question regarding the ethical conduct of this study, you may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 159, (613) 562-5841 or ethics@uottawa.ca.

There are two copies. Please keep one for your records. Thank you for your time and consideration.

Signature (participant)

Date

Signature (researcher)

Date

AX Discrimination Task

Experimental trials: “same” (each appearing 5 times, for a total of 40 trials)

dental 1 / dental 1
dental 2 / dental 2
dental 1 / dental 2
dental 2 / dental 1
retroflex 1 / retroflex 1
retroflex 2 / retroflex 2
retroflex 1 / retroflex 2
retroflex 2 / retroflex 1

Experimental trials: “different” (each appearing 5 times, for a total of 40 trials)

dental 1 / retroflex 1
dental 2 / retroflex 2
dental 1 / retroflex 2
dental 2 / retroflex 1
retroflex 1 / dental 1
retroflex 2 / dental 2
retroflex 1 / dental 2
retroflex 2 / dental 1

Control trials: “same” (each appearing 2 times, for a total of 16 trials)

labial 1 / labial 1
labial 1 / labial 2
labial 2 / labial 1
labial 2 / labial 2
velar 1 / velar 1
velar 1 / velar 2
velar 2 / velar 1
velar 2 / velar 2

Control trials: “different” (each appearing 2 times, for a total of 16 trials)

labial 1 / velar 1
labial 1 / velar 2
labial 2 / velar 1
labial 2 / velar 2
velar 1 / labial 1
velar 1 / labial 2
velar 2 / labial 1
velar 2 / labial 2

Control trials: “different” (each appearing 1 time, for a total of 16 trials)

dental 1 / labial 1
labial 2 / dental 1
dental 1 / velar 1
velar 2 / dental 1
dental 2 / labial 1
labial 2 / dental 2
dental 2 / velar 1
velar 2 / dental 2
labial 1 / retroflex 1
retroflex 1 / labial 2
velar 1 / retroflex 1
retroflex 1 / velar 2
labial 1 / retroflex 2
retroflex 2 / labial 2
velar 1 / retroflex 2
retroflex 2 / velar 2

Appendix 7 – Artefact Correction and Rejection

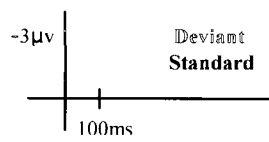
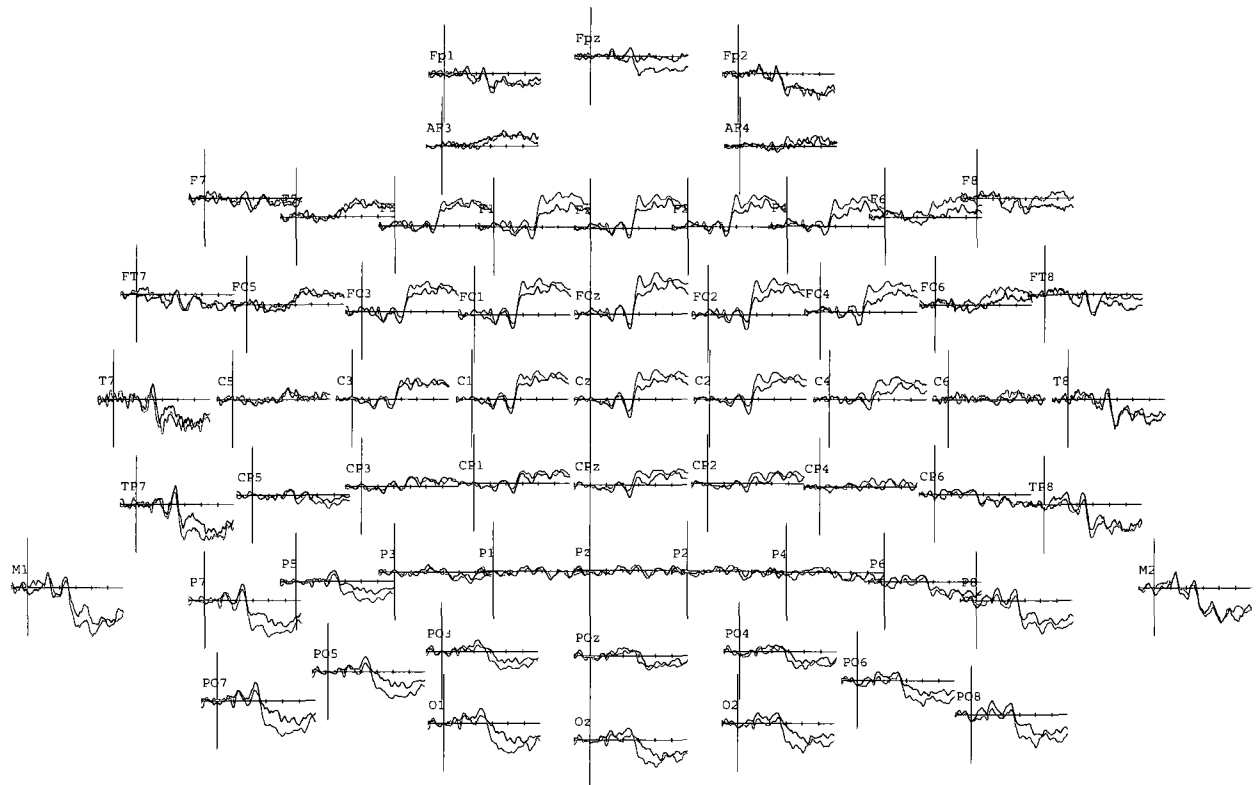
Pre-Test						
	Average % corrected		Average % rejected		Total number of trials included per participant	
	Standard	Deviant	Standard	Deviant	Standard	Deviant
Control	19	19	2	2	75	74
Monolinguals	15	15	1	1	76	76
Late biling.	10	10	4	4	76	76
Early biling.	12	8	2	2	73	73
Multilinguals	20	19	2	3	75	76

Post-Test						
	Average % corrected		Average % rejected		Total number of trials included per participant	
	Standard	Deviant	Standard	Deviant	Standard	Deviant
Control	10	8	6	8	75	75
Monolinguals	18	19	1	1	71	70
Late biling.	12	13	4	4	74	75
Early biling.	11	11	2	2	72	72
Multilinguals	15	14	2	3	75	76

Test of Transfer						
	Average % corrected		Average % rejected		Total number of trials included per participant	
	Standard	Deviant	Standard	Deviant	Standard	Deviant
Control	19	16	4	5	72	71
Monolinguals	16	18	1	1	75	74
Late biling.	12	12	3	4	77	77
Early biling.	12	10	1	2	74	73
Multilinguals	13	12	5	5	76	76

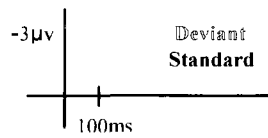
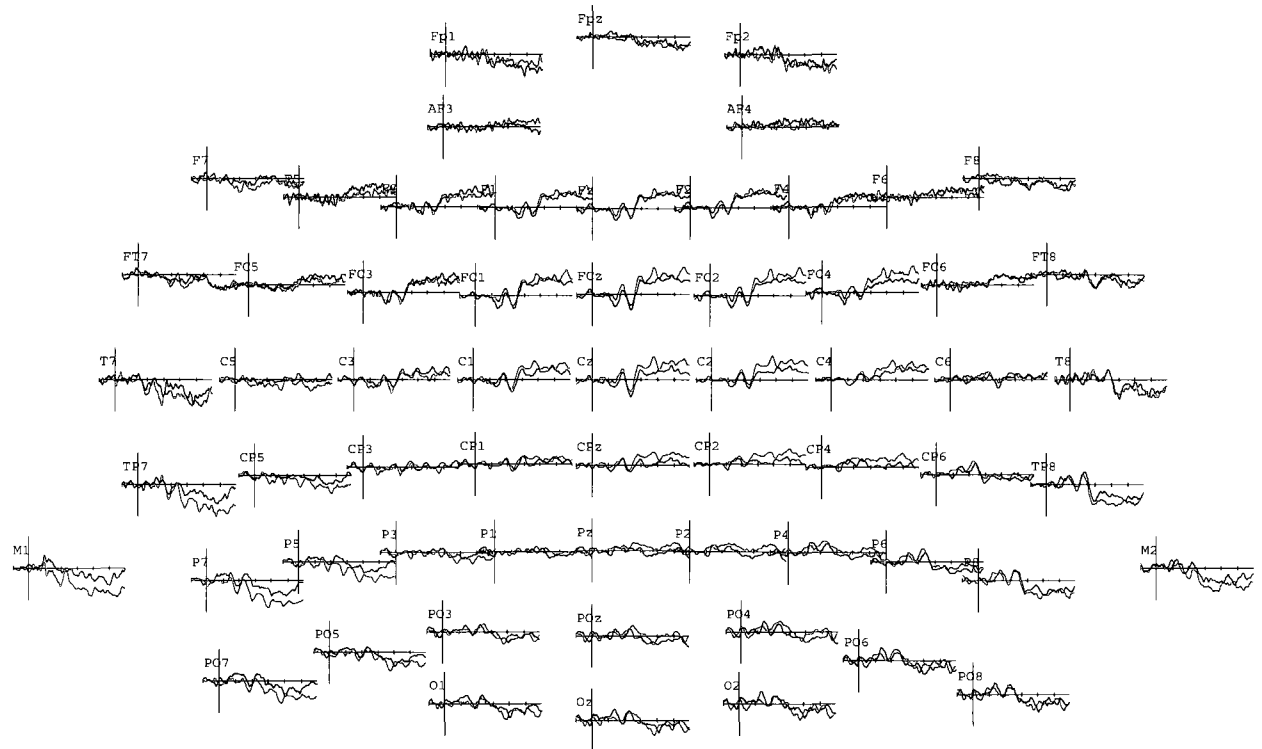
Pre-Test

Control Group



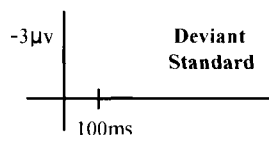
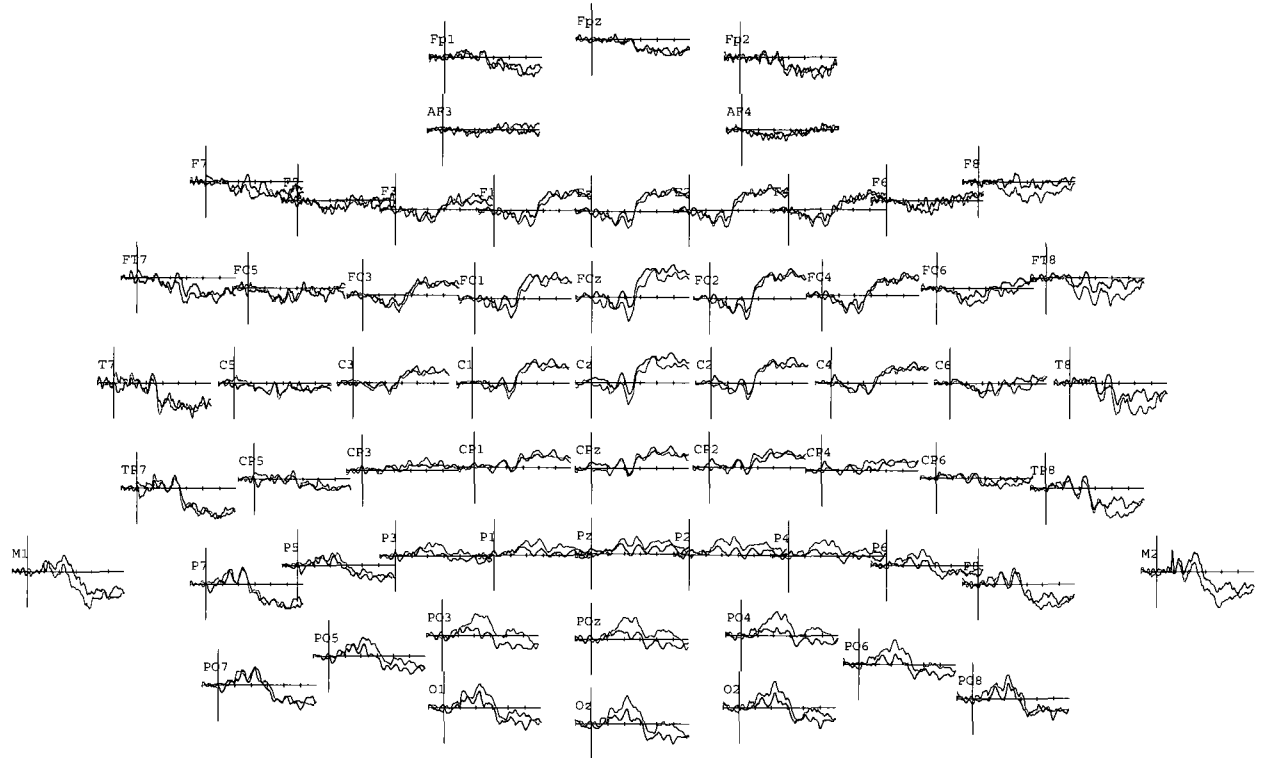
Pre-Test

Monolinguals



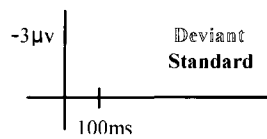
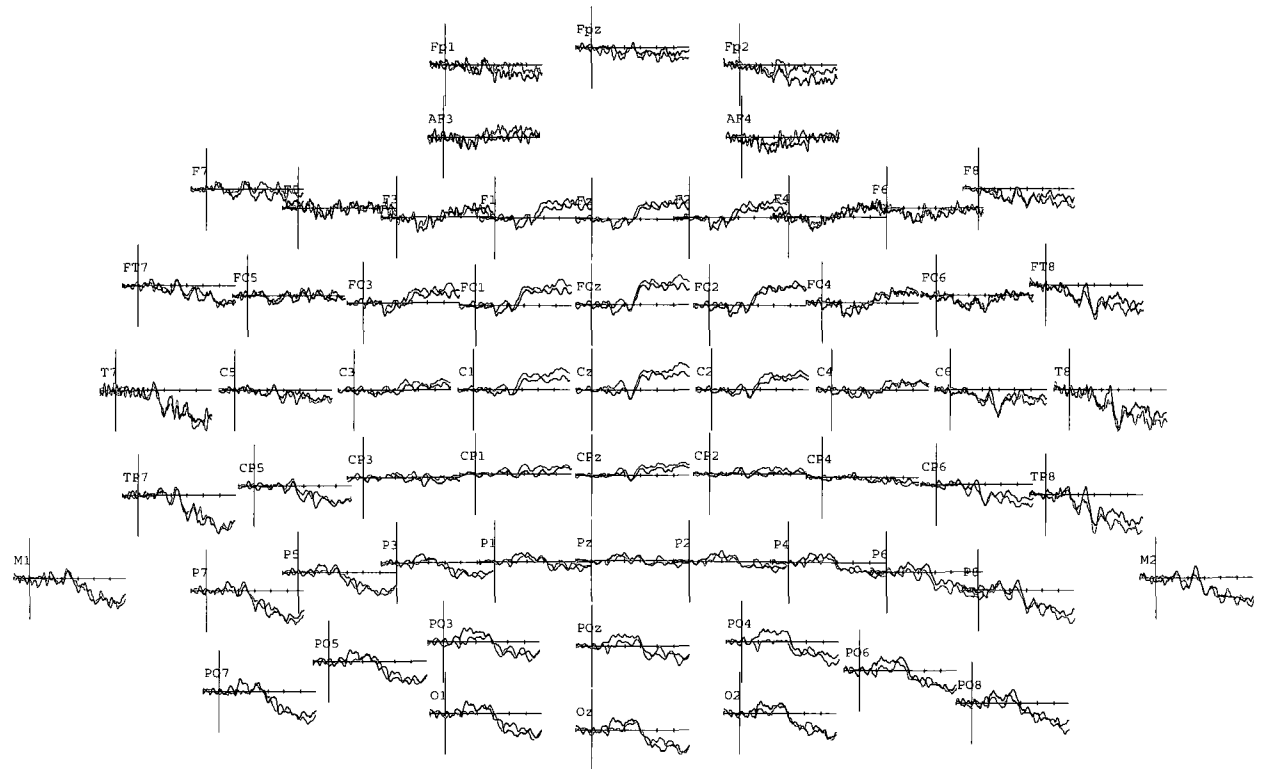
Pre-Test

Late Bilinguals



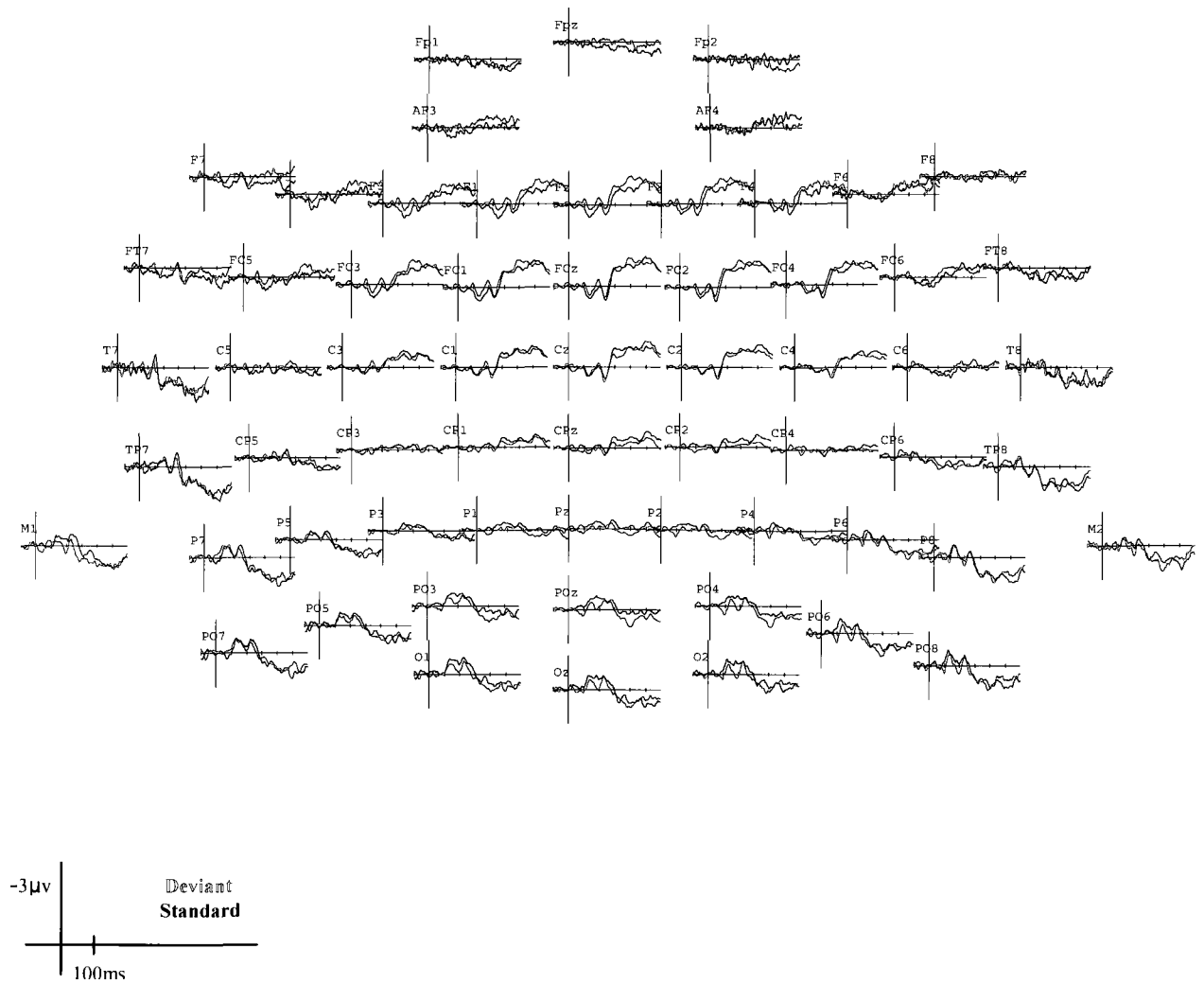
Pre-Test

Early Bilinguals



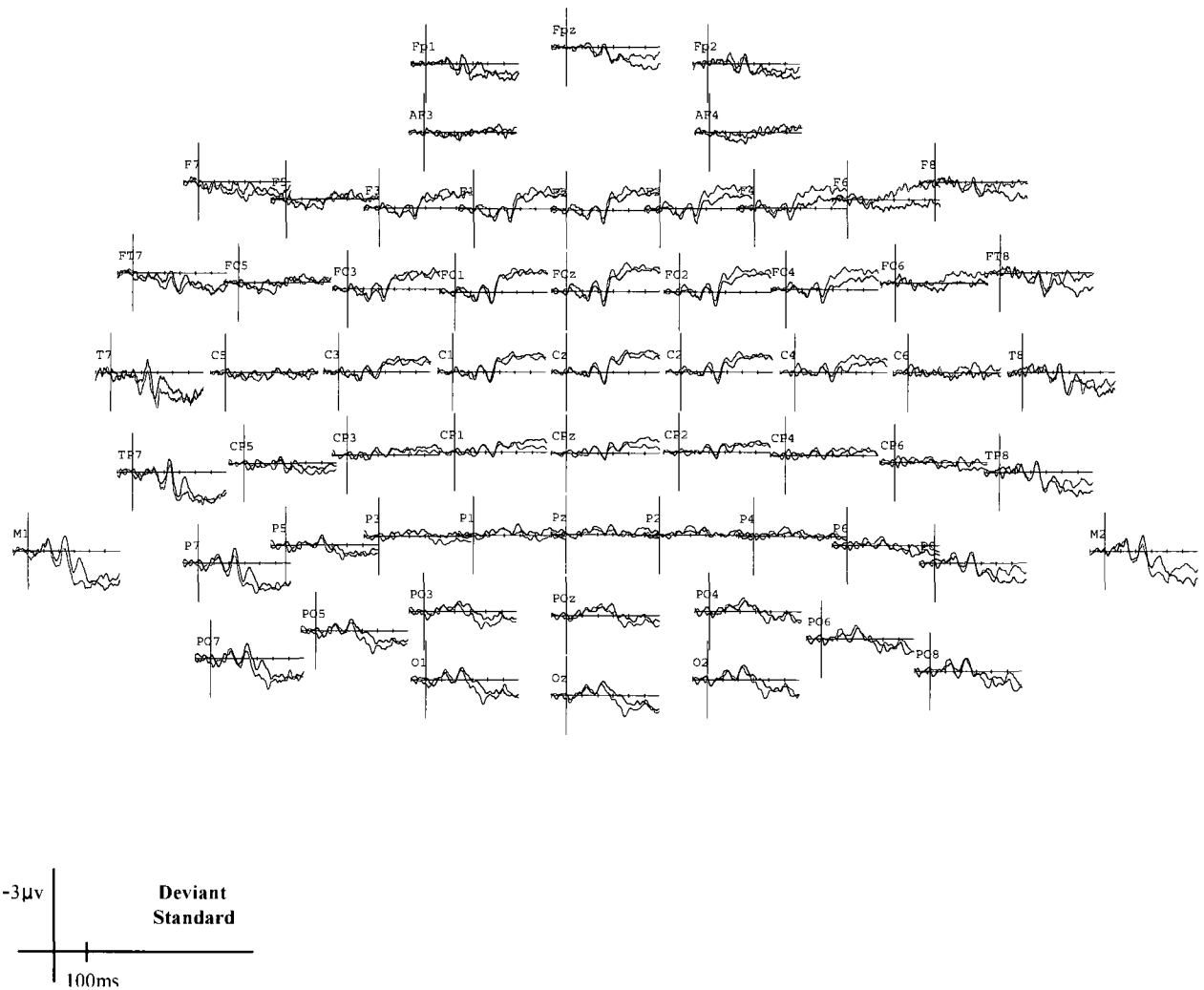
Pre-Test

Multilinguals



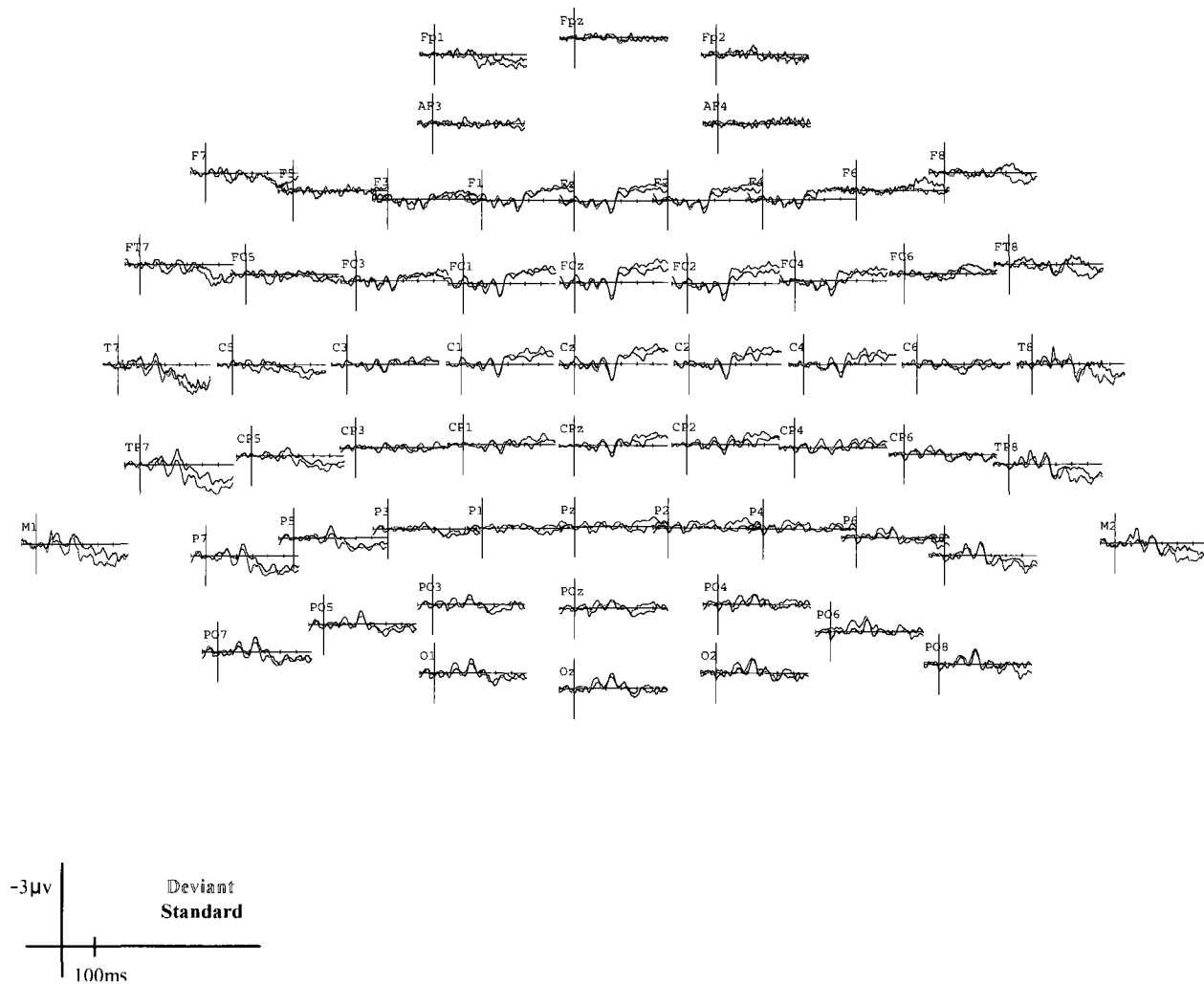
Post-Test

Control Group



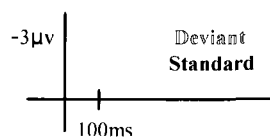
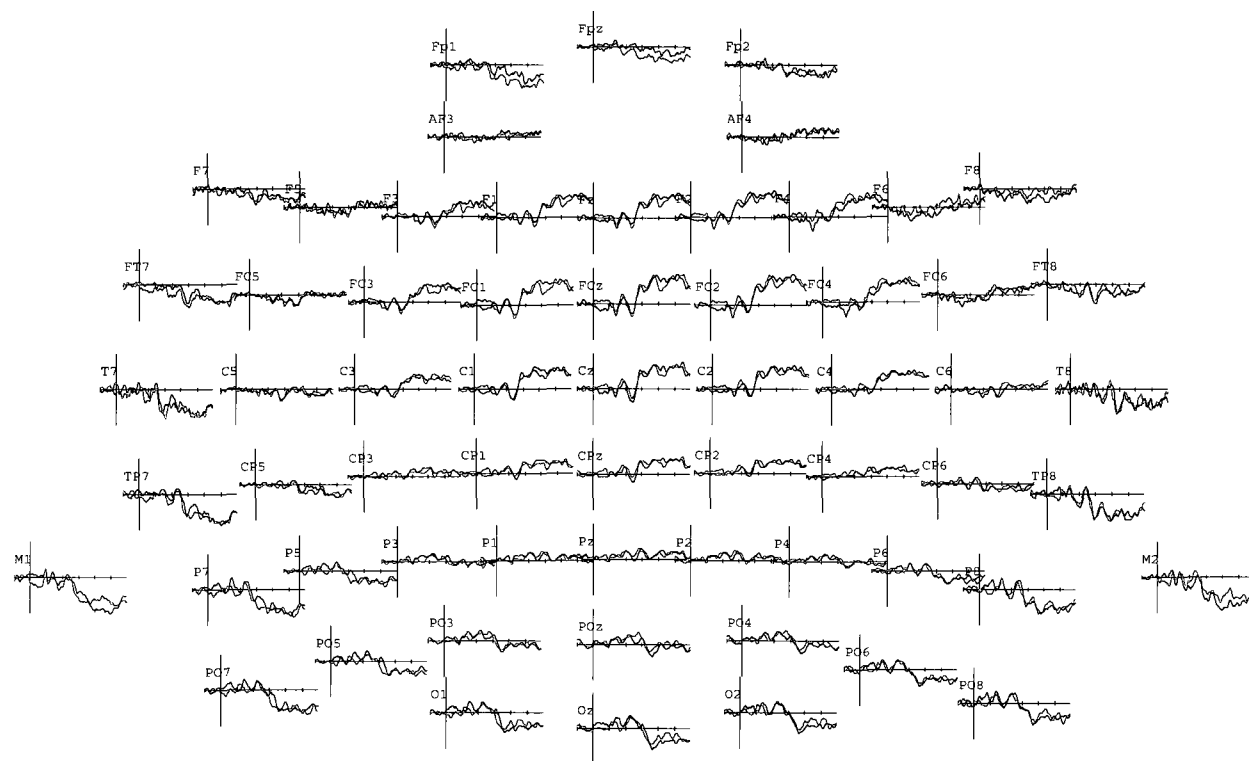
Post-Test

Monolinguals



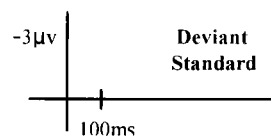
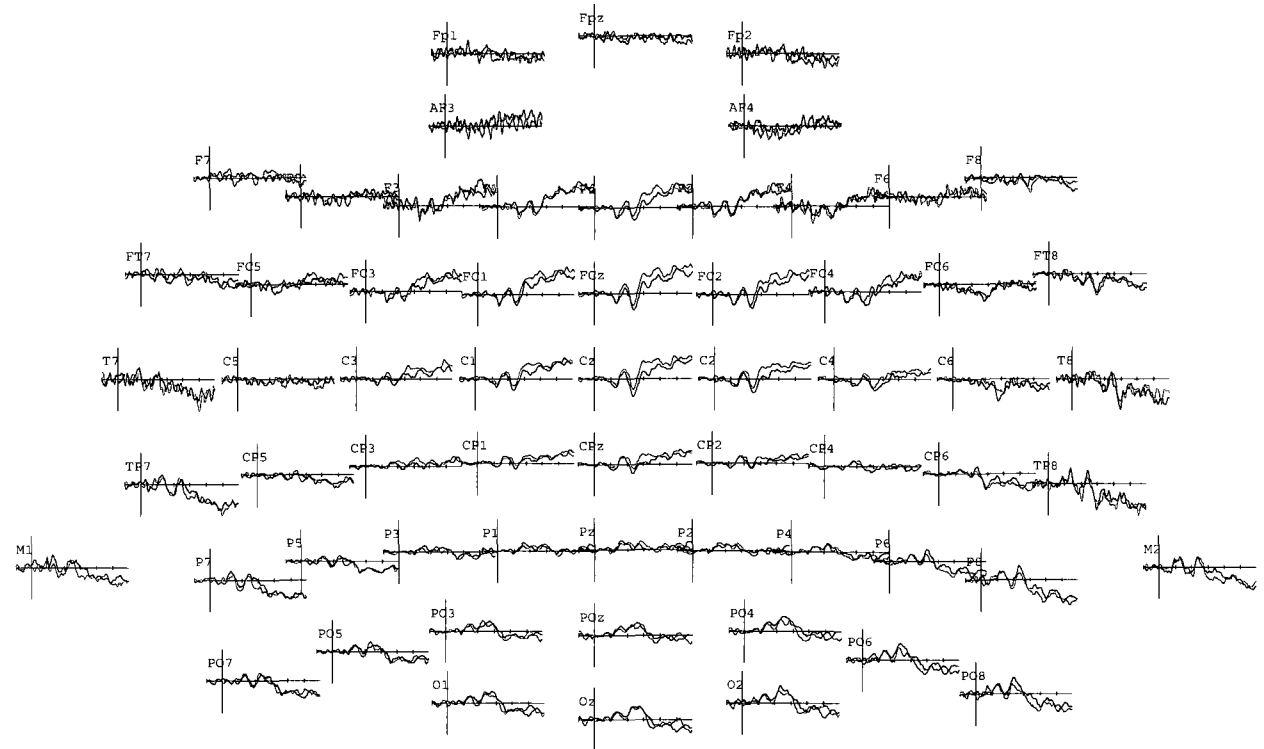
Post-Test

Late Bilinguals



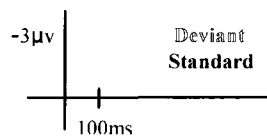
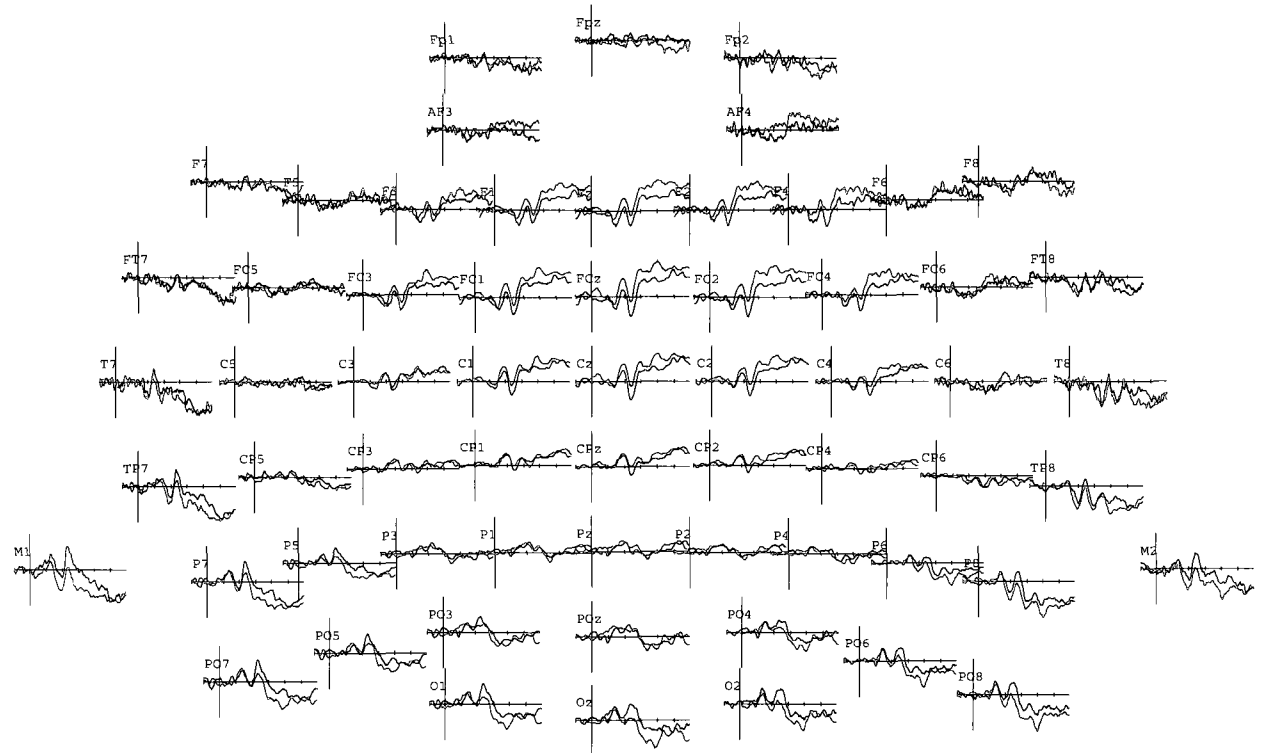
Post-Test

Early Bilinguals



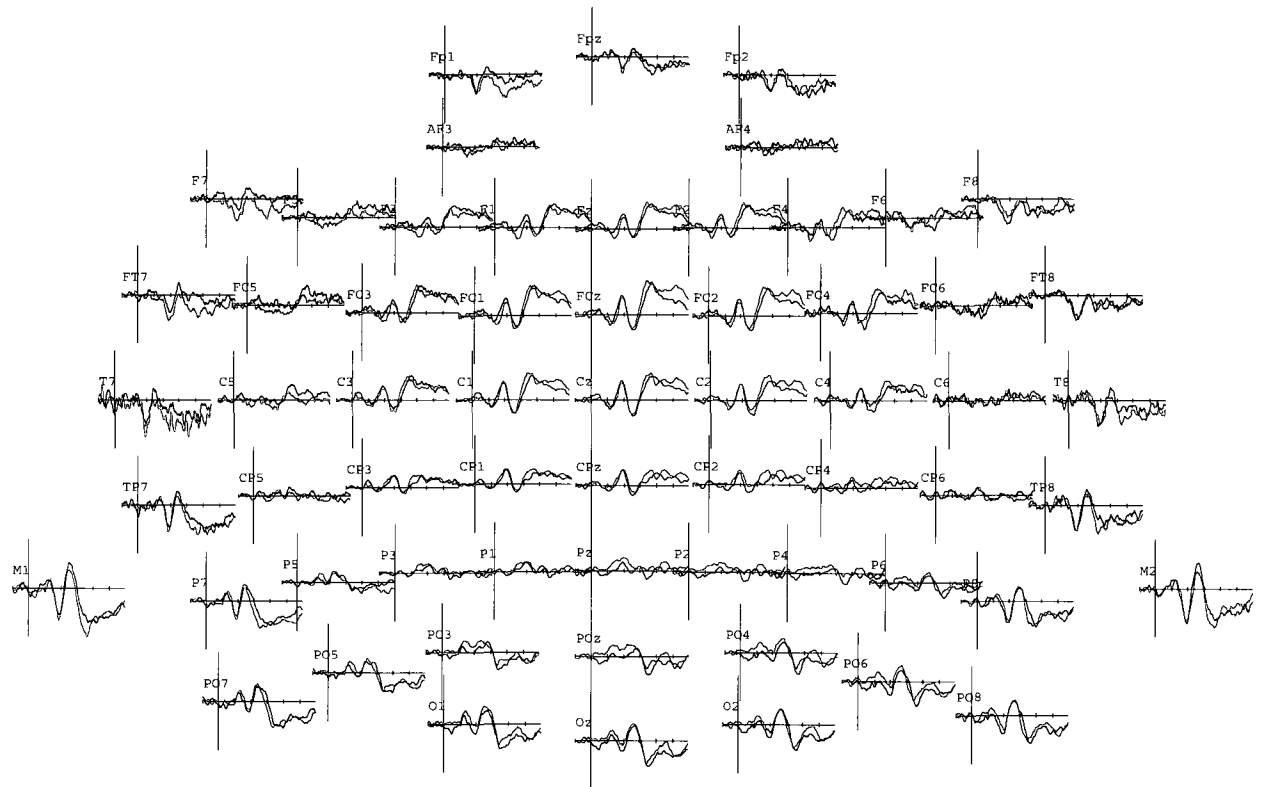
Post-Test

Multilinguals



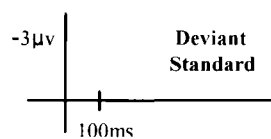
Test of Transfer

Control Group



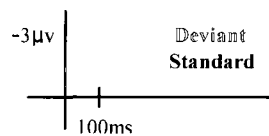
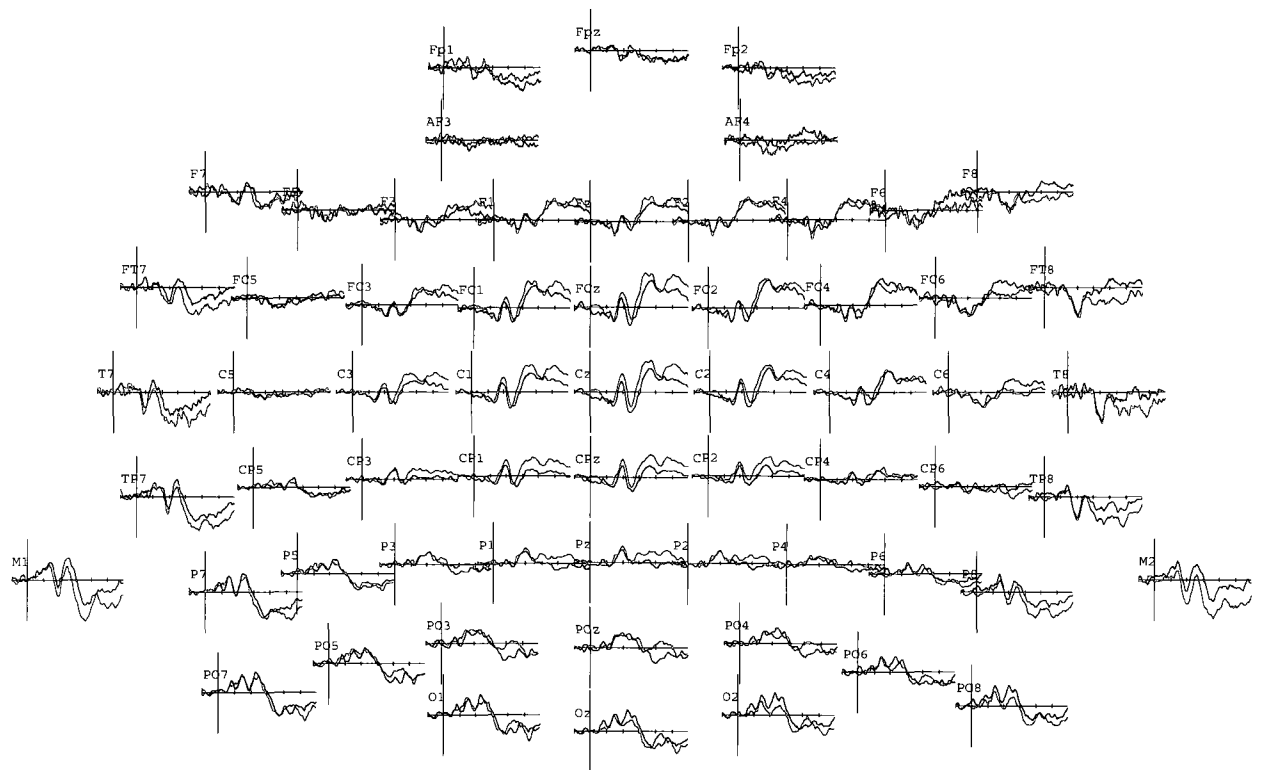
Test of Transfer

Monolinguals



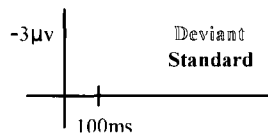
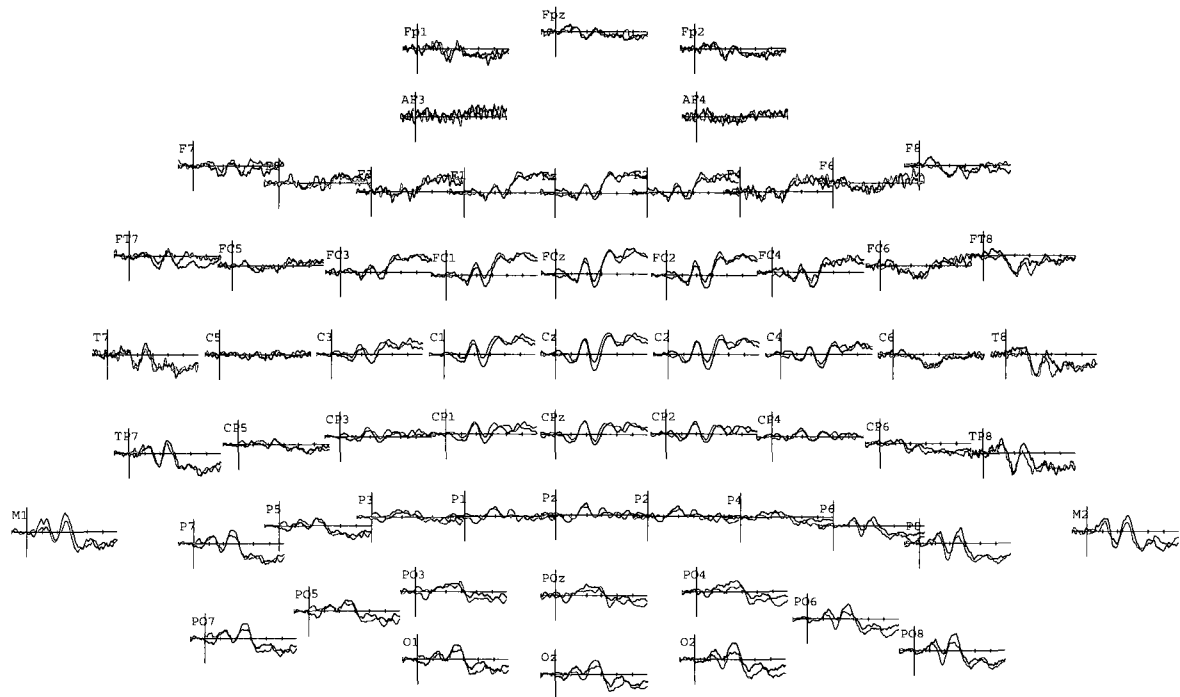
Test of Transfer

Late Bilinguals



Test of Transfer

Early Bilinguals



Test of Transfer

Multilinguals

