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Varying degrees of plasticity in different subsystems within language

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There are periods in development during which experience plays its largest role in shaping the eventual structure and function of mature language-processing systems. These spans of peak cortical plasticity have been called "sensitive periods." Here, we describe a series of studies investigating the effects of delays in second language (L2) acquisition on different subsystems within language. First, we review the effects of the altered language experience of congenitally deaf subjects on cerebral systems important for processing written English and American Sign Language (ASL). Second, we present behavioral and electrophysiological studies of L2 semantic and syntactic processing in Chinese-English bilinguals who acquired their second language over a wide range of ages. Third, we review semantic, syntactic, and prosodic processing in native Spanish and native Japanese late-learners of English. These approaches have provided converging evidence, indicating that delays in language acquisition have minimal effects on some aspects of semantic processing. In contrast, delays of even a few years result in deficits in some types of syntactic processing and differences in the organization of cortical systems used to process syntactic information. The different subsystems of language which rely on different cortical areas, including semantic, syntactic, phonological, and prosodic processing, may have different developmental time courses that in part determine the different sensitive period effects observed.

Humans, in comparison to other animals, go through a protracted period of post-natal development that lasts at least 15 years (Chugani & Phelps, 1986; Huttenlocher, 1990). During this extended time period, there is opportunity for experience to interact with neural development such that neurocognitive systems are eventually established to optimally process the types of information these systems are exposed to during development. The developmental time

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span during which experience has its greatest effects on how the mature system will eventually function has been called a "sensitive or critical period." A full characterization of sensitive periods is important for basic understanding of the role of experience in neural and cognitive development and can contribute to the design of educational and rehabilitative programs by identifying which systems are most influenced by environmental input and when they are most affected.

Much of our current knowledge about plasticity during neural development has come from studies of sensory systems (Rauschecker & Marler, 1987). Different neural systems and associated behavioral capabilities are affected by environmental input at highly variable time periods, supporting the idea that they develop along distinct time courses (Harwerth *et al.*, 1986; Maurer & Lewis, 1998; Mitchell, 1981; Neville & Bavelier, 1999). Importantly, the sensitive periods and developmental time courses for subsystems within major sensory systems can differ dramatically. For example, visual processes thought to arise within the retina (e.g., the sensitivity of the scotopic visual system) display relatively short sensitive periods. By contrast, binocular functions that rely on later developing cortical neurons display considerably longer sensitive periods (Harwerth *et al.*, 1986). Cross-modal plasticity also shows considerable variability within a single domain. For example, congenitally deaf and hearing individuals have very similar brain responses to stimuli presented to the center of the visual field and to color information. By contrast, congenitally deaf individuals display enhanced behavioral responses, electrophysiological responses, and cerebral blood flow to peripheral visual stimuli (Bavelier *et al.*, 2000; Neville & Bavelier, 1999, 2001).

The concept of sensitive periods has been central in the study of language processing and language acquisition. Penfield and Roberts (1959) were among the first to discuss the idea that children might be better language learners than adults. Lenneberg (1967) suggested that just as maturational constraints define a period of time during which visual experience is necessary for setting up a normal visual processing system, there may be a period of time in development during which language experience is critical for setting up normal linguistic processing systems. He presented evidence from patients with left-hemisphere lesions that occurred early or late in development and showed that children (younger than 9 years of age) inevitably recovered language function after a unilateral lesion, whereas adults with the same types of lesions failed to fully recover. These data suggest that children, unlike adults, retain the cortical plasticity in both hemispheres necessary to acquire language. Additionally, evidence from a few children not exposed to normal language input until later in life due to either extreme abuse (Curtiss, 1977) or deafness (Curtiss, 1989;

Emmorey & Corina, 1990; Mayberry & Fischer, 1989; Newport, 1990) indicates that exposure to a first language early in life is necessary for full language attainment.

Similarly, studies focusing on second language acquisition have shown that children are more likely to attain native-like proficiency in a second language than are adults (Flege *et al.*, 1999; Lamendella, 1977; Long, 1990; Patkowski, 1994; Scovel, 1988; Singleton, 1989). The study of second language acquisition offers an opportunity to determine the boundaries of the sensitive period for language since individuals who learn second languages at a wide range of ages are readily available. However, the results of some studies have suggested that native-like language processing cannot be attained by second language learners no matter how early they began learning the second language (Cutler *et al.*, 1983, 1989, 1992; Pallier *et al.*, 1997; Sebastian-Galles & Soto-Faraco, 1999), while other studies find that at least some adult second language learners are able to perform some language tasks in a native-like manner (Birdsong, 1999; Bongaerts, 1995). From these studies, it is not clear whether the offset of the sensitive period for language is extremely early in life (less than 1 year of age), very late in life (continuing into adulthood), or does not exist at all. The lack of a single age after which native-like language processing cannot be achieved has been used to argue that there is no sensitive period for language. However, this argument fails to address two issues: first, the fact that some individuals of any age fail to attain a specific aspect of language does not disprove the hypothesis that there is a peak in plasticity during development in which native-like attainment of a language is more likely; second, the argument ignores the possibility that the time window for a sensitive period for language may differ for different subsystems within language as is the case for the development of the visual system (as noted above). To address this hypothesis, we review here research that has assessed the effects of age of acquisition on different subsystems within language, including semantic, syntactic, and phonological processing.

The literature on phonetic and prosodic processing suggests that experience with a language very early in life is necessary for native-like performance. For example, studies of pronunciation have shown that delays of as little as 4 years in exposure to a second language can result in an accent in that second language even after decades of use (Flege *et al.*, 1999; Yeni-Komshian *et al.*, 1997). Furthermore, there is evidence that perception of the sounds of a second language is not native-like even for those who are exposed to the second language as early as 3 or 4 years of age (Pallier *et al.*, 1997; Sebastian-Galles & Soto-Faraco, 1999). Studies of young infants listening to sounds in their native language and a nonnative language indicate that, by the end of the first year of

life, infants show categorical perception that is specific to the language to which they have been exposed (Best, 1993; Kuhl, 1993; Kuhl *et al.*, 1992; Werker & Tees, 1992, 1999). Since phonological perception is already influenced by language experience within the first year of life, it is possible (although not necessary) that this defines the sensitive period for phonological processing. Although more research will be necessary to determine the exact offset of a phonological processing sensitive period, it is clear that this offset occurs early in life, perhaps before the age of 4.

The few studies that specifically address the effects of age of acquisition on syntactic processing suggest that the sensitive period for this subsystem of language may also be within the first decade of life. In several of the case studies in which first language acquisition was delayed, deficits specific to syntactic processing were reported (Curtiss, 1977, 1989; Newport, 1990). In these studies, children who did not acquire a first language until they were 4 to 6 years old showed deficits in some types of grammatical processing in their first language as adults. Studies of second language acquisition provide corroborating evidence: children who began learning a second language at 8 to 10 years of age scored lower on tests of grammar in that second language (Johnson & Newport, 1989). In fact, deficits in making grammaticality judgements on some types of sentences have been found in adults who acquired their second language as early as 3 years of age (Weber-Fox & Neville, 1996). As with phonological processing, more research will be necessary to precisely characterize the sensitive period for syntactic processing, as well as the types of syntactic processing that are most affected by a lack of experience with a given language during the sensitive period. However, the evidence to date clearly suggests that at least some types of grammatical processing require early experience.

In contrast, semantic processing does not seem to depend on early exposure to a language. Research has shown that people who learn either a first or second language later in life are able to learn new lexical items in that language (Curtiss, 1977, 1989; Newport, 1990) and are able to judge whether or not sentences in that language make sense (Weber-Fox & Neville, 1996). These data suggest that there may not be a sensitive period for semantic and lexical processing, or that the sensitive period for this type of language skill may extend well into adulthood.

While behavioral testing can be used to determine if delays in language learning affect the ability to process language, neuroimaging studies can be used to investigate whether or not first and second language processing makes use of the same neural systems. For example, cortical stimulation studies have found that stimulation of at least some cortical areas affects only one of a bilingual's two languages (Ojemann, 1983; Ojemann & Whitaker, 1978).

However, for the most part, these studies have not compared the different types of linguistic processing (semantic, syntactic, and phonological) necessary to perform the tasks used. As with behavioral studies, this lack of task specificity has created a contradictory picture, with some studies finding no differences in processing native and nonnative languages (Chee *et al.*, 1999; Illes, *et al.*, 1999; Klein *et al.*, 1995, 1999) and others suggesting that different cortical areas are used for languages learned early and late in life (Kim *et al.*, 1997; Klein *et al.*, 1994; Perani *et al.*, 1996).

This evidence suggests that the sensitive periods for subsystems within language are nonidentical and that characterizing the development of language processing will require characterizing each of these subsystems separately. Taking such an approach may help to clarify the currently contradictory results from neuroimaging studies of first and second language processing. In addition, it may be that even within specific subsystems different aspects of language processing are differentially affected by delays in learning. For example, within the syntactic subsystem, delays in language learning seem to have less of an effect on the ability to process word order than other types of syntactic information (Weber-Fox & Neville, 1996). Therefore, it will be important to use a variety of tasks that tap into different types of lexical, syntactic, and phonological processing to determine which aspects of language processing are most affected by delays in language learning.

Below we present evidence on these issues, first from a comparison of semantic and syntactic processing and related neural organization in English and ASL by deaf and hearing individuals who acquired these languages at different ages. Next we describe a series of studies concerning the effects of age of acquisition on grammaticality and meaningfulness judgments and on the event-related brain potentials (ERPs) to different word classes, violations of grammar, and violations of meaning within sentences. Finally, we present a series of behavioral and ERP studies in which we assess the ability of native and nonnative speakers to use stress-pattern, syntax, and lexical information to segment speech.

5.1 Studies of congenitally deaf individuals

The comparison of the processing of English in deaf and hearing subjects provides an important opportunity to study sensitive periods during development. While hearing subjects learn English from birth, deaf individuals are introduced to English much later. ERPs recorded while deaf and hearing subjects read English sentences suggest that semantic and grammatical processing are differentially vulnerable to altered early language experience (Neville *et al.*,

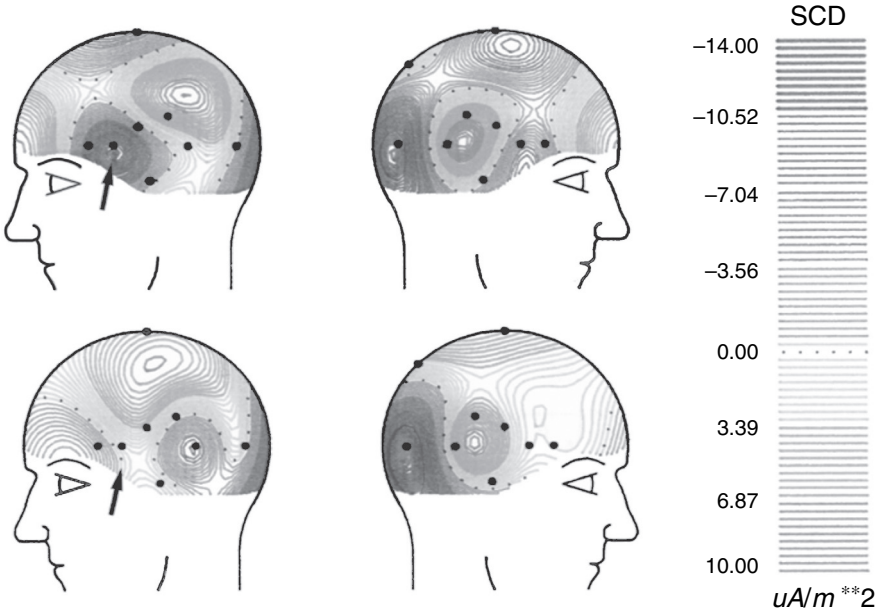

Figure 5.1 Distribution of current flow for the N280 peak elicited by closed-class words in English. Maps in the top row show the prominent response in the left hemisphere of hearing subjects (blue, marked by arrow). Bottom row maps display results from congenitally deaf individuals who lack the response (arrow) (Figure 5.9 from Neville *et al.*, 1992; permission requested from *Cerebral Cortex*) (see also color plate section). PRAQ1

1992). Deaf subjects displayed ERPs to open-class words and other semantic information in English that were similar to those observed when normal hearing subjects processed English. These results suggest that aspects of semantic processing are robust following deaf subjects' altered early language experience. In contrast, deaf subjects' ERPs to closed-class words that carry grammatical information were markedly different from those of hearing subjects reading the same sentences. Deaf subjects' ERPs lacked the negative (N280) potential over anterior regions of the left-hemisphere and did not display any evidence of left hemisphere advantage (Figure 5.1). These results are in accord with the idea that language experience has different effects on the development of the several different brain systems that mediate language. Brain systems that mediate grammatical aspects of language processing appear to be more sensitive to altered language experience. This idea is supported by our observation that deaf subjects whose grammar skills were excellent displayed an N280 response that was prominent and asymmetrical just as in normal hearing subjects (Neville, 1991).

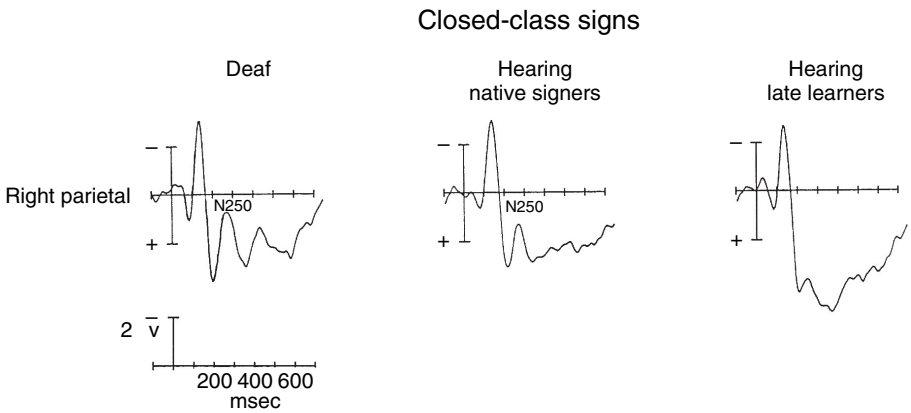

Figure 5.2 ERPs to closed-class signs in ASL sentences from 10 deaf, 10 hearing native signers, and 10 late-learners of ASL. Recordings from parietal areas of the right hemisphere (Figure 7.6 from Neville & Bavelier, 1999; permission requested from MIT Press).

PRAQ2

Recently, we have employed ERPs to pursue this hypothesis further and to obtain evidence on the question of whether the strongly biased role of the left hemisphere in language occurs independently of the structure and modality of the language first acquired (Neville *et al.*, 1997, 1998). ERPs recorded in response to open- and closed-class signs in ASL sentences displayed similar timing and anterior/posterior distributions to those observed in previous studies of English. But, whereas in native speakers of English responses to closed-class English words were largest over anterior regions of the left hemisphere; in native signers closed-class ASL signs elicited activity that extended posteriorly over both the left and right hemispheres. These results imply that the acquisition of a language that relies on spatial contrasts and the perception of motion may result in the inclusion of right-hemisphere regions. As seen in Figure 5.2, both hearing and deaf native signers displayed this effect. However, hearing people who acquired ASL in the late teens did not show this effect, suggesting there may be a limited time (sensitive) period when this type of organization for grammatical processing can develop.

In fMRI studies comparing sentence processing in English and ASL we also observed evidence for biological constraints and effects of experience on the mature organization of the language systems of the brain. As seen at the top of Figure 5.3, when hearing adults read English (L1), there is robust activation within the left but not the right hemisphere and in particular within the left inferior frontal (Broca's) region. When deaf people read English (L2), we do not observe activation of these regions within the left hemisphere (Figure 5.3, middle). Is the absence of left-hemisphere activation in the deaf linked to lack of

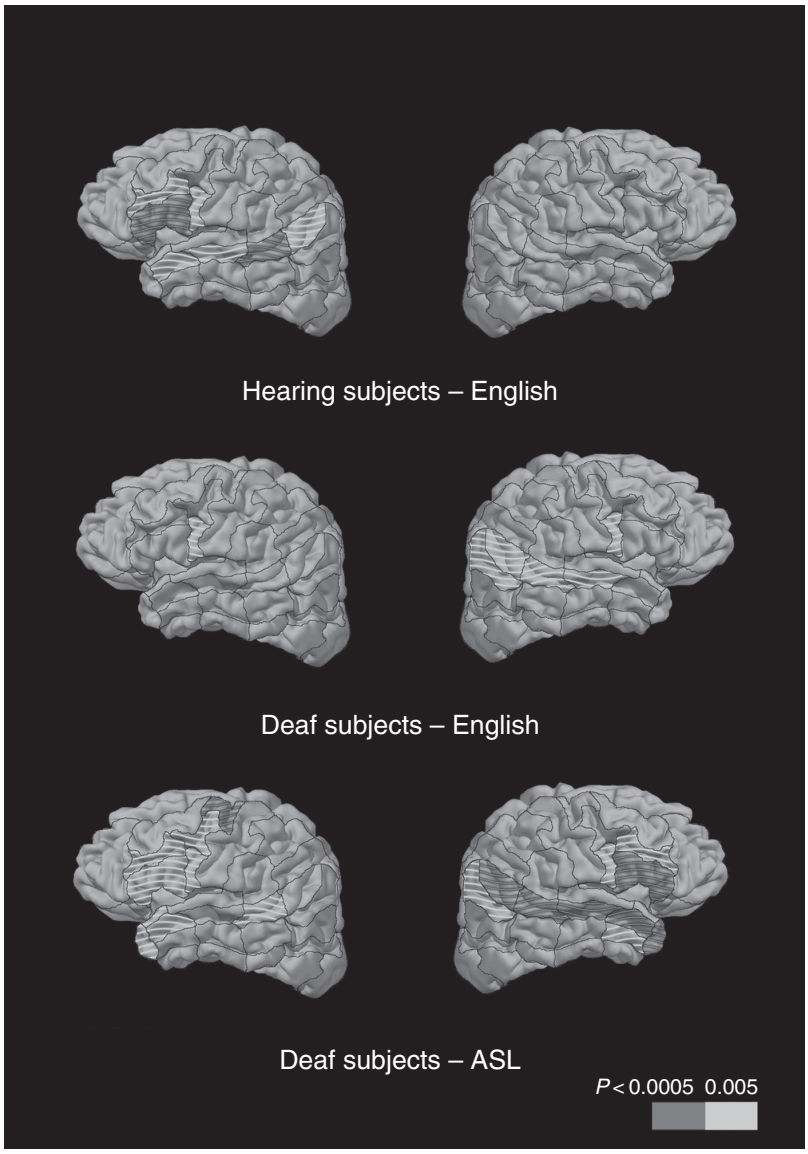

Figure 5.3 Cortical areas showing increases in blood oxygenation on fMRI when normal hearing adults read English sentences (top), when congenitally deaf native signers read English sentences (middle), and when congenitally deaf native signers view sentences in their native sign language (American Sign Language) (bottom) (Figure 7.7 from Neville & Bavelier, 1999; permission requested from MIT Press) (see also color plate section).

PRAQ3

auditory experience with language or to incomplete acquisition of the grammar of the language? ASL is not sound-based, but displays each of the characteristics of all formal languages including a complex grammar that makes extensive use of spatial location and hand motion (Klima & Bellugi, 1979). Studies of the same deaf subjects when viewing sentences in their native ASL clearly show activation within the same inferior frontal regions of the left hemisphere that are active when native speakers of English process English (Figure 5.3, bottom). These data suggest a strong biological bias for these neural systems to mediate grammatical language regardless of the structure and modality of the language acquired. However, if the language is not acquired within the appropriate time window, this strong bias is not expressed. Biological constraints and language experience interact epigenetically, as has been described for many other systems in developmental biology.

The fMRI data also indicate a robust role for the right hemisphere in processing ASL. These results suggest that the nature of the language input, in this case the co-occurrence of location and motion information with language, shapes the organization of the language systems of the brain. The right-hemisphere activation observed in deaf native signers viewing ASL sentences was also observed in hearing individuals who acquired ASL as a native language from their deaf parents (Neville *et al.*, 1998). However, hearing signers who acquired ASL after the age of 15 did not show the same extent of right-hemisphere activation as did native signers (Newman *et al.*, 2001). These results imply that like other oral–aural, natural languages the acquisition of aspects of ASL display sensitive period effects.

5.2 Syntactic and semantic processing in hearing bilinguals

As reviewed above, converging evidence points to specialized subsystems for language processing that are differentially sensitive to delays in second language learning. Based on the behavioral findings of linguistic proficiency in second language learners (Johnson & Newport, 1989; Newport, 1988) as well as the neurophysiological evidence for language processing in hearing and deaf individuals (Neville *et al.*, 1992), we hypothesized that the neural subsystems for syntactic processing would be more vulnerable to delays in language learning compared to those associated with semantic processing. This hypothesis was tested in two ways. One approach was to observe differential effects on processing violations in syntactic structure and in semantic expectation. In another experiment, the effects of delays in second language immersion were examined for processing two different word classes that were used appropriately in sentences.

Both of these paradigms examined the ERP responses obtained from Chinese-English bilingual speakers and monolingual English speakers (Weber-Fox &

Neville, 1996, 2001). The bilingual participants were grouped according to the age at which they were initially immersed in English: 1–3, 4–6, 7–10, 11–13, and after 15 years of age. Age of immersion corresponded, for the most part, to the time that these individuals arrived in the US. All of the bilingual participants had been immersed in English for a minimum of 5 years at the time of testing. The years of English experience naturally ranged from the highest for the bilinguals who were immersed in English at the youngest age (1–3 group – mean of 17.9 years) to progressively shorter durations. However, it should be noted that the two latest learning groups (11–13 and > 15) had comparable years of experience with English (means of 7.8 and 7.6 years, respectively).

5.2.1 *Linguistic proficiency*

Consistent with previous behavioral studies (Johnson & Newport, 1989; Newport, 1988), the English proficiency demonstrated by these bilingual participants was related to their age of English immersion (Weber-Fox & Neville, 1996, 2001). This relationship was reflected in both the participants' self-rated proficiency scores as well as their performance on tests of knowledge of English syntax and grammar. The self-rated proficiency scores were virtually identical for comprehension and speaking abilities (Weber-Fox & Neville, 1996, 2001). Specifically, the bilingual speakers who were immersed in English prior to the age of 11 years rated themselves more proficient and nearly perfect in English as compared to Chinese. The bilingual speakers who arrived in the US around the age of puberty (11–13 years) rated themselves equally proficient in English and Chinese, and interestingly did not consider themselves perfect in either of their languages. The latest learning bilinguals, who were immersed in English after the age of 15 years, rated their proficiency in Chinese as perfect and higher than their abilities in English. The results of standardized testing in English also revealed that longer delays in second language learning were associated with reduced English proficiency. Performance scores on the CELF Sentence Structure Subtest (Semel-Mintz & Wiig, 1982) revealed reduced proficiency for bilingual speakers who were immersed in English as early as 7–10 years of age (Weber-Fox & Neville, 1996, 2001). Figure 5.4 illustrates the syntactic proficiency of the bilingual groups compared to monolingual English speakers.

5.2.2 *Semantic and syntactic anomalies*

Sentence stimuli that had previously revealed distinct neural subsystems for syntactic and semantic processing in monolinguals were utilized (Neville *et al.*, 1991). This paradigm allowed the comparison of ERPs that were elicited by violations in syntactic structure, specifically a phrase structure violation (e.g., "The boys heard Joe's <u>about</u> stories Africa"), and violations in semantic

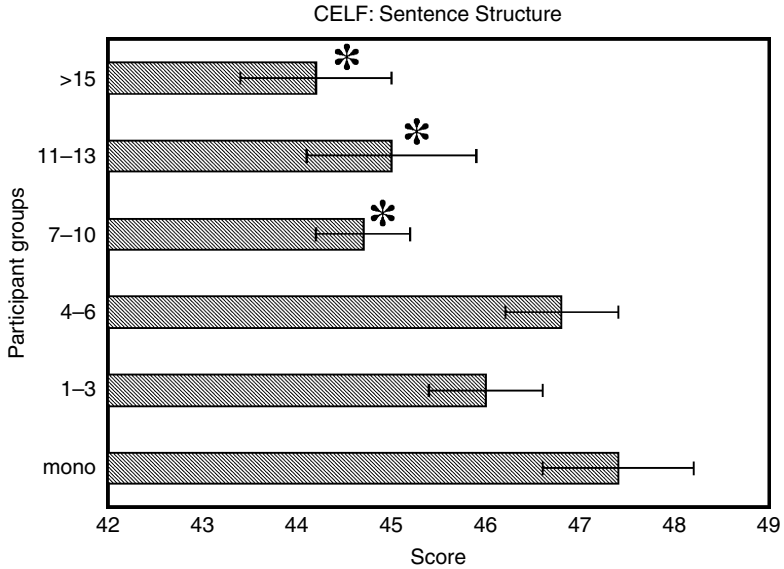

Figure 5.4 Scores for the CELF: Sentence Structure Subtest for monolinguals and each of the bilingual groups. Asterisks indicate decreased syntactic proficiency in English for bilinguals who were immersed in English after 7 years of age.

expectation (e.g., "The boys heard Joe's orange about Africa"). Participants were also presented with control sentences that contained no violations of English syntax or semantics (e.g., "The boys heard Joe's *stories about* Africa"). The randomized sentences were displayed one word at a time (2 words/second) on a monitor while the participants' electroencephalographic (EEG) signals were recorded. The underlined words in the examples of the phrase structure violations and semantic anomalies indicate the comparison points for ERPs elicited by those violation conditions and their control sentences.

After reading each sentence, participants were asked to judge whether or not the sentence was a "good English sentence." The accuracies in detecting syntactic and semantic violations were differentiated among the bilingual groups (Weber-Fox & Neville, 1996). Consistent with our predictions, the judgment accuracy for phrase structure violations was affected by shorter delays in second language exposure compared to the detection of semantic anomalies. While only the latest learning bilingual group (>15) performed less accurately than the monolinguals in detecting semantic anomalies, the detection of phrase structure violations was reduced in bilinguals who were immersed in English as young as 7–10 years old (Weber-Fox & Neville, 1996).

Consistent with these behavioral findings, the ERP responses elicited by phrase structure violations and semantic anomalies displayed differential sensitivity to delays in second language learning. The electrophysiological

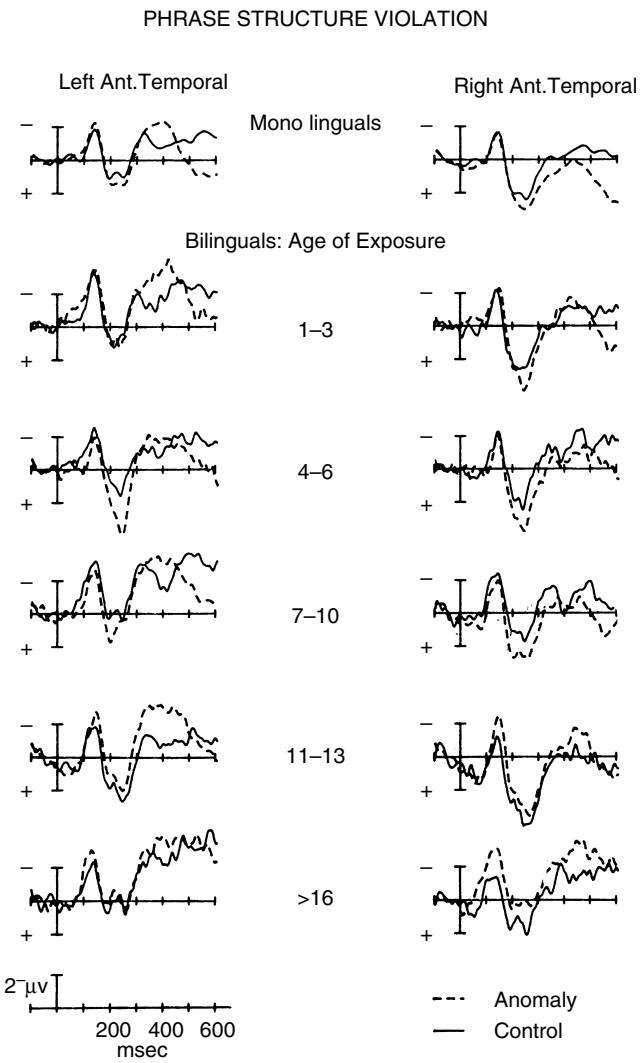

Figure 5.5 ERPs elicited by phrase structure violations for monolinguals and each of the bilingual groups. Responses over the left and right anterior temporal electrode sites are illustrated. Negative potentials are plotted upward (from Weber-Fox & Neville, 1999; permission requested from Lawrence Erlbaum). PRAQ4

responses to phrase structure violations showed marked changes in the distribution, amplitude, and actual presence of ERP components (Weber-Fox & Neville, 1996). For example, the asymmetry in the left anterior negativity (LAN) between 300 and 500 ms elicited by phrase structure violations in monolinguals was decreased with longer delays in English immersion, and a more bilateral response emerged in the late-learners (Figure 5.5). As Figure 5.5 illustrates, longer delays in second language learning were associated with increased

involvement of the right hemisphere between 300 and 500 ms. This result suggests that less specialized and more broadly distributed language systems are used by later learning bilinguals for this task.

Another aspect of the ERP responses elicited by phrase structure violations was sensitive to delays in second language learning as well: the syntactic positive shift (SPS). The SPS, measured in the 500–700 ms latency window, was absent in the ERPs of bilinguals immersed in English after 11 years of age (also depicted in Figure 5.5). Further analysis revealed that the ERPs from bilinguals immersed in English at around the time of puberty (11–13 years) displayed an SPS in a later latency range (700–900 ms). However, no evidence of an SPS was found in the ERPs of the latest learning group (>15 years), despite a similar number of years of experience with English. These results suggest that later learners of English might have been processing and interpreting these syntactic violations in an atypical manner.

In contrast, semantic anomalies elicited characteristic N400 responses for each of the bilingual groups, regardless of age of second language immersion (Figure 5.6). No differences in the distribution or amplitude of the N400 across the bilingual groups were found. However, the peak latency of the N400 was longer for the bilinguals immersed in English after 11 years of age, suggesting a slight slowing in processing (approximately 20 ms) for the latest learning bilingual groups.

Thus, both the behavioral and neurophysiological results for detecting linguistic violations indicate that the subsystems for processing syntactic and semantic information are differentially impacted by delays in second language immersion. Further, both the behavioral and electrophysiological results indicate that the subsystems for syntactic processing are more sensitive and impacted to a greater extent by delayed immersion compared to the subsystems utilized for semantic interpretation.

5.2.3 Closed- and open-class words

In a complementary study, the effects of delays in second language learning were examined for closed- and open-class words that were used appropriately in sentences (Weber-Fox & Neville, 2001). These two word classes were selected because they have different functions during sentence processing. Open-class words primarily provide referential meaning and are more closely related to semantic processing. In contrast, closed-class words provide information regarding the relationships between open-class words and are primarily related to syntactical processing (Hagoort *et al.*, 1999; Neville *et al.*, 1992). As in the study described above, effects of delayed language immersion could thus be observed separately for the functional neural subsystems associated with

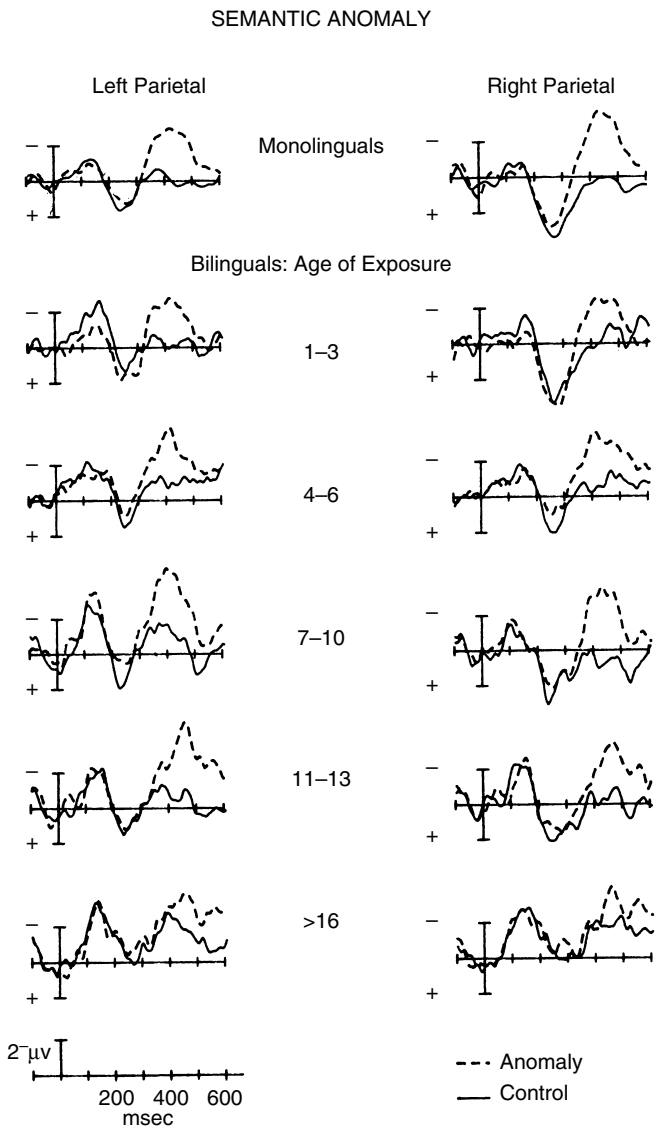

Figure 5.6 ERPs elicited by violations in semantic expectations for monolinguals and each of the bilingual groups. Responses over the left and right parietal electrode sites are illustrated. Negative potentials are plotted upward (from Weber-Fox & Neville, 1999; permission requested from Lawrence Erlbaum). PRAQ5

syntactic and semantic processing. Therefore, this study extended the observations of our previous findings to include processing of words used appropriately in sentences. Given the differential functions of open- and closed-class words in sentence processing and electrophysiological evidence (Neville *et al.*, 1992, 1993), we hypothesized that the neural subsystems associated with these two

word classes would be differentially affected by delays in second language immersion. Evidence from deaf individuals (Neville *et al.*, 1992) and children with language impairment (Neville *et al.*, 1993) predicted that the neural subsystems associated with processing closed-class words would be impacted to a greater extent by delays in second language immersion than the neural systems associated with processing open-class words.

Parallel to the previous study (Weber-Fox & Neville, 1996), participants were grouped according to the age at which they were initially immersed in English. Monolingual and bilingual speakers read 120 sentences previously used in a study of hearing and deaf individuals (Neville *et al.*, 1992). The sentences were presented one word at a time on a monitor. Half of them ended in a semantic anomaly and participants indicated whether the sentences made sense or not. With the exception of the first and last words in the sentences, each of the words was categorized as open- or closed-class. The ERPs were then averaged separately for each word class (Weber-Fox & Neville, 2001).

Similar to previous findings (Neville *et al.*, 1992), the ERPs elicited by closed- and open-class words displayed distinctions in functional neural subsystems in monolingual and bilingual speakers; that is, the responses to open-class words were characterized by a bilateral negativity, peaking around 350 ms after word onset that was largest over posterior regions. In contrast, the ERPs elicited by closed-class words displayed an earlier negative peak (280 ms after word onset) that was lateralized over anterior and temporal regions of the left hemisphere (Weber-Fox & Neville, 2001).

The effects of delays in second language immersion were evidences by the peak latencies of the N280 over the left hemisphere. Peak latencies of the N280 were later (approximately 35 ms) with delays in second language learning as short as 7 years (Weber-Fox & Neville, 2001) (Figure 5.7). Further analyses revealed that these latencies were significantly correlated with English syntactic proficiency as measured by the CELF Sentence Structure Subtest (Semel-Mintz & Wiig, 1982; see Weber-Fox & Neville, 2001, for further details). In contrast, the latencies and distribution of the ERPs elicited by open-class words (N350) were similar across monolinguals and each of the bilingual groups. No age of immersion effects were observed for open-class words (Weber-Fox & Neville, 2001).

Consistent with our findings for processing syntactic and semantic violations, the findings for closed- and open-class words support the hypothesis that delays in second language immersion do not uniformly affect neural subsystems for language. Furthermore, whether participants were processing linguistic violations or different word classes used appropriately in sentences, the neural subsystems for syntactic/grammatical functions were more sensitive to shorter delays in second language learning. Thus, these studies support the

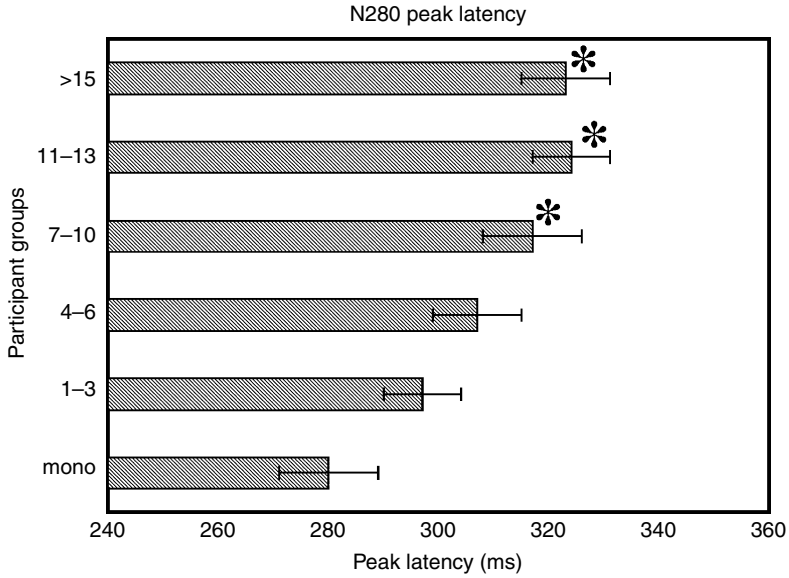

Figure 5.7 Peak latencies of the N280 elicited by closed-class words for monolinguals and each of the bilingual groups. Measures are illustrated for the left anterior temporal electrode site. Asterisks indicate longer latencies for bilinguals who were immersed in English after 7 years of age.

hypothesis that the timing of second language experience has differential degrees of impact in the development of specialized neural subsystems for language.

5.3 Speech segmentation in bilinguals

Unlike with written English, people do not usually leave spaces or pauses between words in spoken English. However, listeners must somehow determine where boundaries occur in continuous speech in order to map the sounds onto familiar lexical items. Many different types of information in speech have been hypothesized to be useful in this process of speech segmentation, including lexical information (Norris *et al.*, 1995), syntactic information (Cole *et al.*, 1980), and, in at least some languages, stress pattern information (Cutler & Butterfield, 1992). In a recent study, we showed that all of these types of information are not only available in English speech, but also that native speakers use each of these cues to determine where word onsets occur in continuous speech (Sanders & Neville, 2000). Since native speakers used lexical, syntactic, and stress-pattern cues to perform the segmentation task, we employed the same task as a measure of nonnative speakers' abilities to use

each of these aspects of language as well. Thus, the segmentation task provided an opportunity to measure the effects of delays in second language acquisition on an additional subsystem of language – prosody.

Based on the literature reviewed above, we hypothesized that nonnative speakers would be able to use lexical information to segment English speech, even if they did not learn the language until late in life. In contrast, we expected that nonnative speakers who learned English late in life would not be able to use syntactic information to the same extent as native speakers. Based on the research of phonological processing and the finding that nonnative speakers fail to learn to use syllabification as a segmentation cue (Cutler *et al.*, 1983, 1989, 1992), we hypothesized that nonnative speakers would not be able to use stress pattern to the same extent as native speakers. We were also interested in the ways in which the stress-pattern characteristics of the native language might affect nonnative speakers' ability to use English stress-pattern as a segmentation cue.

5.3.1 Behavioral study

Five groups of participants were included in this study: monolingual English speakers (ME), native Japanese late-learners of English (JLE), native Spanish late-learners of English (SLE), native Japanese speakers who had little experience with English and were tested in Japan (JJ), and monolingual Spanish speakers (MS). Both groups of late-learners began learning English after the age of 12 but had lived in an English-speaking country for an average of 6 years. The two groups of nonnative speakers were selected such that one native language (Japanese) would provide no experience with lexical stress as it is used in English, and the other native language (Spanish) would provide experience with lexical stress, but with a different stress pattern than is typical in English.

All subjects were asked to perform the same task. For each sentence that they heard, they were first given a target phoneme or phoneme combination. They were asked to press one button if they heard the target at the beginning of a word or nonword in the subsequent sentence. They were asked to press a different button if they heard the target in the middle of a word or nonword. The amount of lexical information available in the sentences was varied by taking normal English sentences (semantic sentence type) and replacing all of the content words with pronounceable nonwords (syntactic sentence type). The amount of syntactic information available in the sentences was varied by taking the syntactic sentences and replacing all of the remaining words and morphemes with nonwords (acoustic sentence type). Prosody was maintained across all three sentence types, but stress pattern was manipulated by including target phonemes in words with normal English stress pattern (strong stress on the

Table 5.1. *Examples of semantic, syntactic, and acoustic sentences*

Condition	Type	Sentence
Target present		
SI	Semantic	In order to recycle *b*ottles you have to separate them.
	Syntactic	In order to lefatal *b*okkers you have to thagamate them.
	Acoustic	Ah ilgen di lefatal *b*okkerth ha maz di thagamate fon.
SM	Semantic	If the only thing in it were to*b*acco it wouldn't cause so much harm.
	Syntactic	If the ilmy shord in it were do*b*atty it wouldn't gaff so much hilm.
	Acoustic	Os fa ilmy shord el ok hon do*b*atty ag hapsel gaff sha nes hilm.
WI	Semantic	The child stopped crying when a *b*alloon was given to her.
	Syntactic	The ferp trepped plawing when a *b*arreal was kaffen to her.
	Acoustic	Sa ferp trepp plawel ron i *b*arreal hof kaffem gi wem.
WM	Semantic	I saved money since lowgrade tim*b*er worked for this project.
	Syntactic	I cheft rono since miltrok del*b*er meld for this plassig.
	Acoustic	O cheft rono zalf miltrok del*b*er meld sith foch plassig.
Target absent		
	Semantic	Try looking under the afghan for the toy you lost.
	Syntactic	Qui medding under the ithdon for the kay you moft.
	Acoustic	Qui medden amkel fa ithdon sal cha kay wa moft.

Note: All example sentences use /b/ as the target phoneme which is indicated by italics in the sentences. SI = Strong stress, Initial position; SM = Strong stress, Medial position; WI = Weak stress, Initial position; WM = Weak stress, Medial position.
Source: From Sanders and Neville (2000)

initial syllable and weak stress on the medial syllables) and words with an infrequent English stress pattern (weak stress on the initial syllable and strong stress on the medial syllable). Examples of each sentence type and stress patterns are shown in Table 5.1. The groups' abilities to use lexical information were measured by comparing performance on the semantic sentences, which contained complete lexical information, and the syntactic sentences, which had degraded lexical information. Use of syntactic information was measured by comparing performance on the syntactic sentences with performance on the acoustic sentences, which had less syntactic information available. The use of stress pattern to segment speech was measured by comparing performance on targets that occurred in words with normal English stress pattern to performance on those that occurred in words with infrequent English stress pattern.

As reported previously (Sanders & Neville, 2000; Sanders, *et al.*, 2002), the comparison of performance on the semantic and syntactic sentence types (shown in Figure 5.8) revealed that both groups of late-learners of English (JLE, SLE) used lexical information to the same extent as native English speakers, as

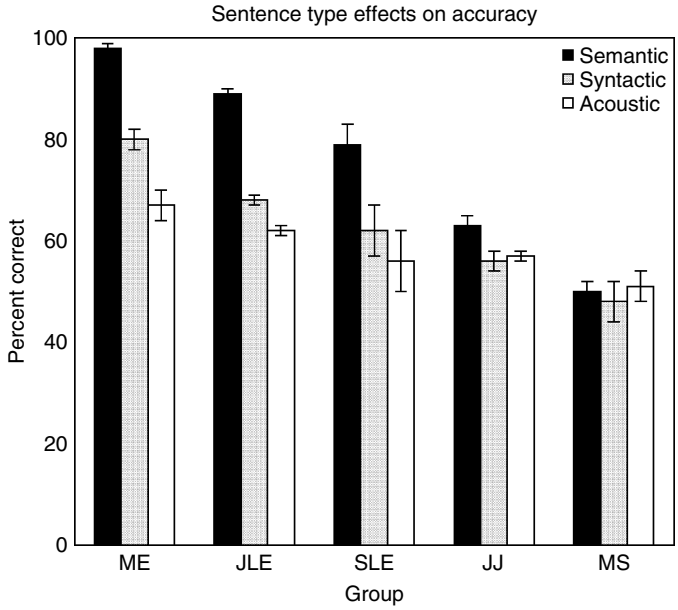

Figure 5.8 Percent correct on the speech segmentation task for semantic, syntactic, and acoustic sentence types. ME = Monolingual English speakers; JLE = native Japanese late-learners of English; SLE = native Spanish late-learners of English; JJ = native Japanese speakers tested in Japan (native Japanese speakers with little English experience); MS = Monolingual Spanish speakers. Both groups of late-learners of English used lexical information to the same extent as native English speakers (difference in performance on semantic and syntactic sentence types). However, the late-learners of English did not use syntactic information to the same extent (difference in performance on syntactic and acoustic sentence types).

hypothesized. The fact that both groups who did not know English (JJ, MS) did not use the lexical information to as great an extent as the native English speakers confirms that lexical information, and not acoustic factors that could be processed regardless of language experience, was the key difference between the two sentence types.

In contrast to the lexical information, a comparison of the syntactic and acoustic sentence types (also shown in Figure 5.8) revealed that none of the nonnative speakers (JLE, SLE, JJ, and MS) used syntactic information to the same extent as native English speakers. These findings support the hypothesis that delays in second language acquisition affect syntactic processing to a greater extent than lexical or semantic processing.

The comparison of normal and infrequent stress pattern (Figure 5.9) revealed that both the acquisition of English and the specific native language acquired affected the ability to use this segmentation cue. First, both groups of

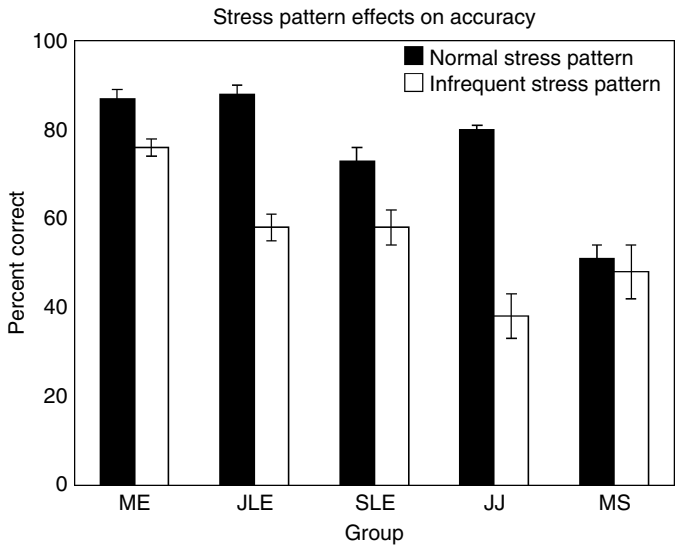

Figure 5.9 Percent correct on the speech segmentation task for normal English stress pattern (strong stress on the initial syllable, weak stress on medial syllables) and an infrequent English stress pattern (weak stress on the initial syllable, strong stress on a medial syllable). ME = Monolingual English speakers; JLE = native Japanese late-learners of English; SLE = native Spanish late-learners of English; JJ = native Japanese speakers tested in Japan (native Japanese speakers with little English experience); MS = Monolingual Spanish speakers. All groups with any experience with English (ME, JLE, SLE, and JJ) were more accurate with normal English stress than infrequent English stress. However, the extent to which stress pattern was used as a segmentation cue depended on the stress pattern characteristics of the native language.

late-learners (JLE, SLE) were able to use stress-pattern to at least the same extent as native English speakers. Second, both groups of native Japanese speakers (JLE, JJ) relied on normal English stress pattern to an even greater extent than the native English speakers did. Third, neither group of native Spanish speakers (SLE, MS) relied on stress pattern to the same extent as either group of native Japanese speakers (JLE, JJ). This pattern of results was interpreted as evidence that stress pattern, and perhaps other prosodic information, can be learned even if exposure to a language that uses lexical stress occurs after the age of 12 and even without many years of experience. Furthermore, the results suggest that the specific type of experience gained with a native language (here, the stress rules) can affect the degree to which similar aspects of a second language are learned and used.

Overall, the results of this behavioral study are consistent with the hypothesis that delays in learning a second language affect syntactic processing to a

greater extent than semantic processing. Additionally, they indicate that at least some types of prosodic processing, specifically stress pattern, can be learned later in life. Although the behavioral study indicates that nonnative speakers used lexical and stress-pattern segmentation cues in ways similar to native speakers, this study does not address the issue of whether or not native and nonnative speakers process these types of information at the same rate or using the same neural systems. To answer this question, the same stimuli were presented to subjects while ERPs were recorded.

5.3.2 *Event-related potential study*

Two groups of subjects were included in this experiment: monolingual English speakers (ME) and native Japanese late-learners of English (JLE). As with the previous study, the native Japanese late-learners of English all began learning English in school in Japan at the age of 12. They continued learning English in school until they moved to the United States and used English as their primary language for an average of 5 years. Both groups of subjects were asked to listen to sentences of the three types described above (semantic, syntactic, and acoustic). They were not given any target phonemes and the only task they completed was to answer "yes" or "no" to the question "Was the word ____ in the previous sentence?" after a randomly selected 5% of the sentences.

Based on the behavioral data described above, we hypothesized that native and nonnative speakers would process semantic information similarly. To test this hypothesis, we compared the ERPs elicited by words in the normal English sentences (semantic) to those evoked by the equivalent nonwords in the syntactic sentences. As reported previously (Sanders & Neville, 2003), in monolingual English speakers, words elicited a greater negativity than nonwords starting by 150 ms after onset in continuous speech (Figure 5.10). This negativity was broadly distributed, but largest at posterior electrode sites over the right hemisphere. The evoked responses to words in comparison to nonwords were equivalent in the native Japanese late-learners of English; that is, a negativity with similar latency and distribution was also evident in this group (Sanders & Neville, 2003). The only differences found in the response to lexical information in the two groups was that the evoked response was of greater amplitude in the native English speakers.

The behavioral data for syntactic processing, unlike lexical processing, indicated that native speakers and late-learners of a language do not process grammatical information in the same way. To further assess this by hypothesis, we compared the ERPs to nonwords in the sentences which retained syntactic structure (syntactic sentences) to the same nonwords in the sentences which contained less syntactic structure (acoustic sentences). In the native English speakers,

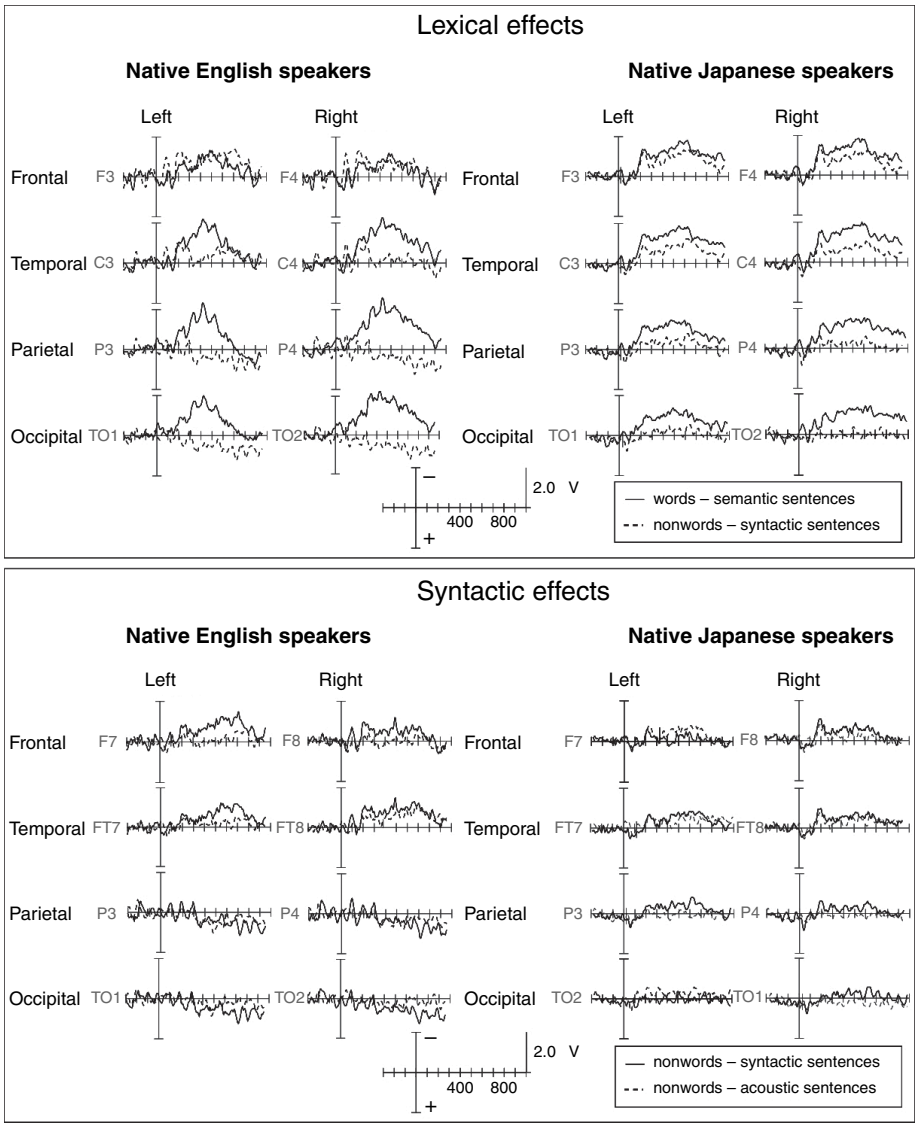

Figure 5.10 ERPs from selected electrode sites for monolingual English speakers and native Japanese late-learners of English. For both groups, words, in comparison to nonwords, elicited a negativity that was largest at posterior areas over the right hemisphere. In contrast, nonwords in the syntactic sentences as compared to nonwords in the acoustic sentences elicited different potentials only in the native English speakers. These differences were found over anterior regions of the left hemisphere.

nonwords in the syntactically intact sentences elicited a negativity that was focally distributed over anterior regions of the left hemisphere (also shown in Figure 5.10). In contrast, no differences in the responses evoked by nonwords in the two types of sentences were found for the native Japanese speakers.

Consistent with the results of the behavioral study, the results of these comparisons indicated that delays in second language learning as long as 12 years had little effect on the ability to use lexical information to segment speech or the cortical organization of processing lexical information. In contrast, these same second language learning delays affected both the ability to use syntactic information in a segmentation task and the cortical organization of syntactic processing.

Lexical stress in English is associated with physical differences in speech such that strongly stressed syllables are both louder and longer than weakly stressed syllables. Since hearing differences in loudness and length do not require specific language experience, it seemed likely that both native and nonnative speakers would show differences in the evoked responses to strongly and weakly stressed syllables. Furthermore, the behavioral evidence indicated that monolingual English speakers and native Japanese late-learners of English are both able to use lexical stress as a cue for speech segmentation. Therefore, we hypothesized that there would be no differences evident in the cortical responses to the two types of stress.

The monolingual English speakers showed a larger negative peak around 100 ms to strong stresses in comparison to weak stresses (shown in Figure 5.11). This difference was predictable in light of research showing that the N100 is larger to louder sounds in comparison to softer sounds. However, the native Japanese late-learners of English showed no differences in the response to strong and weak stresses until after 200 ms. Both groups showed a larger negativity to strong stresses in this later time range. This suggests that, in continuous speech, the early-evoked responses to stress differences may be dependent on language experience. Furthermore, it suggests that delays in learning a language that makes use of lexical stress can affect which neural populations are responsible for processing this type of information.

Additionally, we assessed whether these were differences in the ERPs elicited by word-initial syllable onsets and word-medial syllable onsets (Sanders & Neville, 2003). A comparison of the responses to syllables of equivalent loudness and length in word-initial and word-medial positions, revealed that the word-initial syllables elicited a larger N100, similar to that found for strong stresses, in native English speakers (also shown in Figure 5.11). If the nonnative speakers were segmenting speech in the same way as native speakers, we would expect the same results for the native Japanese speakers. However, for this group, no differences in the responses evoked by word-initial and word-medial syllables were found in the first 300 ms after presentation (Sanders & Neville, 2003). Along with the results for strong and weak stresses, these findings suggest that although both native English speakers and native Japanese late-learners of English were able to perform the speech segmentation task and made use of

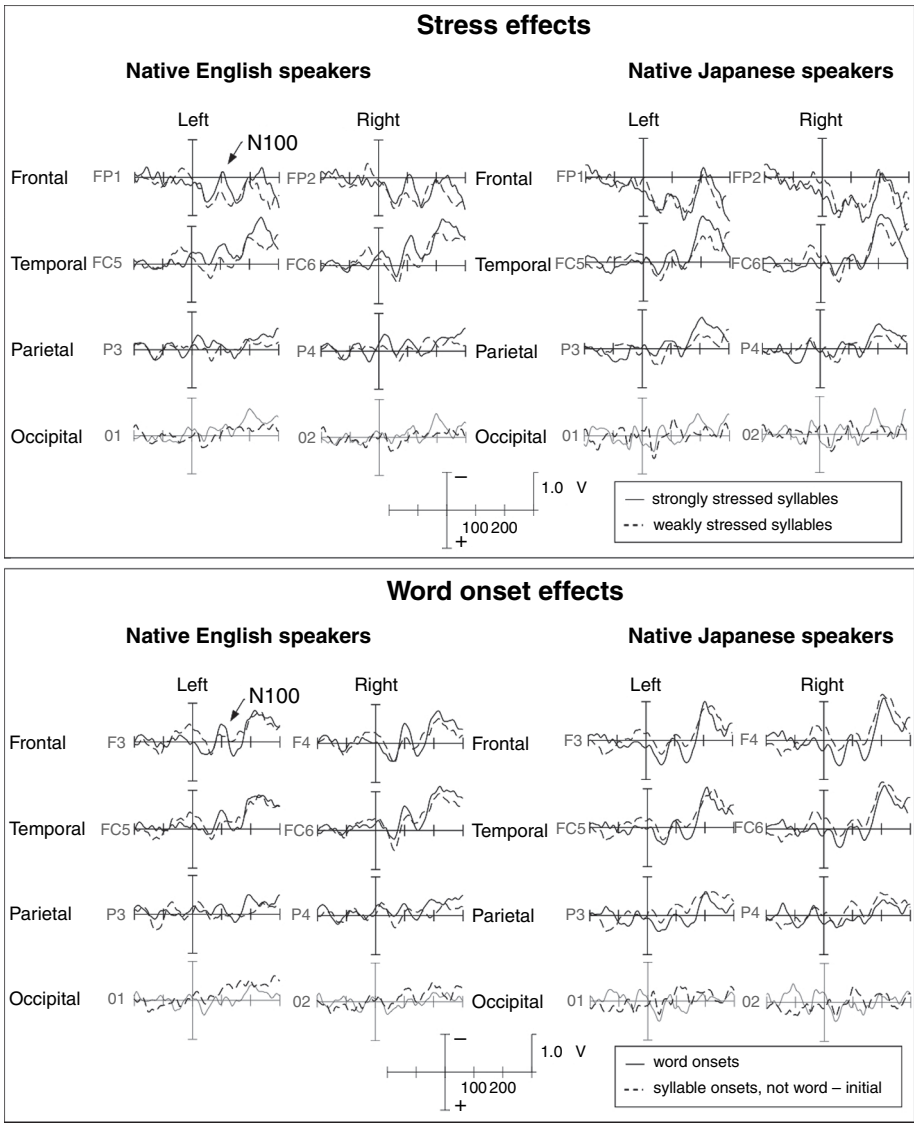

Figure 5.11 ERPs from selected electrode sites for monolingual English speakers and native Japanese late-learners of English. Although strongly stressed syllables elicited a larger negativity than weakly stressed syllables in both groups, this difference was earlier in the monolingual English speakers (100 ms) than in the native Japanese speakers (200 ms). Additionally, a word-onset effect was only found for the native English speakers.

stress-pattern information to do so, processing stress information and segmenting speech take place over different time courses and involve different neural populations for the two groups.

In summary, these studies suggest that delays in second language acquisition affect semantic, syntactic, and prosodic processing in different ways. Results from both behavioral and electrophysiological measures indicate that delays of up to 12 years do not affect at least certain aspects of semantic/lexical processing. In contrast, the same delays in second language acquisition affect the extent to which syntactic information can be used and the way in which syntactic information is processed. Further, the behavioral data indicate that late-learners of English are able to learn to use stress-pattern information; however, the electrophysiological measures indicate that stress information is processed along different time-courses and using nonidentical neural systems by native and nonnative speakers. The differential effects of delays in second language acquisition on lexical, syntactic, and prosodic processing clearly indicate that, as is the case for the sensory systems of the brain, there is considerable variability in the degree to which and the time periods during which different subsystems depend upon and can be modified by input from the environment: some systems retain the ability to change throughout life while others display multiple, different sensitive periods of peak plasticity.

Acknowledgments

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