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The effect of native-language experience on the sensory-obligatory components, the P1–N1–P2 and the T-complex

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Abstract

The influence of native-language experience on sensory-obligatory auditory-evoked potentials (AEPs) was investigated in native-English and native-Polish listeners. AEPs were recorded to the first word in nonsense word pairs, while participants performed a syllable identification task to the second word in the pairs. Nonsense words contained phoneme sequence onsets (i.e., /pt/, /p t/, /st/ and /s t/) that occur in the Polish and English languages, with the exception that /pt/ at syllable onset is an illegal phonotactic form in English. P1–N1–P2 waveforms from fronto-central electrode sites were comparable in English and Polish listeners, even though, these same English participants were unable to distinguish the nonsense words having /pt/ and /p t/ onsets. The P1–N1–P2 complex indexed the temporal characteristics of the word stimuli in the same manner for both language groups. Taken together, these findings suggest that the fronto-central P1–N1–P2 complex reflects acoustic feature processing of speech and is not significantly influenced by exposure to the phoneme sequences of the native-language. In contrast, the T-complex from bilateral posterior temporal sites was found to index phonological as well as acoustic feature processing to the nonsense word stimuli. An enhanced negativity for the /pt/ cluster relative to its contrast sequence (i.e., /p t/) occurred only for the Polish listeners, suggesting that neural networks within non-primary auditory cortex may be involved in early cortical phonological processing.

Keywords

Auditory-evoked potential (AEP); P1–N1–P2 complex; T-complex; Cross-linguistic; Phonetic; Speech perception

1. Introduction

The manner in which acoustic streams of speech are transformed by the cortical auditory pathways into integrated signals necessary for speech perception is not yet well understood. Listeners of a language such as Polish and English have differing auditory experiences with the phoneme sequences that constitute words. Comparison of neural processing to native and

non-native phoneme sequences in native-language groups can determine whether experience with specific phoneme sequences influences stages of cortical speech processing. The current research explores the effects of native-language experience on early stages of cortical speech processing.

P1, N1 and P2 are obligatory components of auditory evoked potentials (AEPs) that index detection of the onset and offset of auditory stimuli (Näätänen and Picton, 1987). The P1, N1 and P2 deflections each have differing underlying neural sources and independent response patterns (for review Crowley and Colrain, 2004; Näätänen and Picton, 1987; Steinschneider et al., 2011a, 2011b) and are modulated by attention (Näätänen et al., 1978; Picton and Hillyard, 1974).

The sequential acoustic features within a word elicit P1–N1–P2 responses, which overlap and result in a signature waveform for the phoneme sequence within the word (Martin and Boothroyd, 1999, 2000; Ostroff et al., 1998). Investigation of the P1–N1–P2 complex to speech has important clinical implications because it can demonstrate cortical access to the acoustic features within the speech signal necessary for speech perception (Martin et al., 2007, 2008).

The T-complex is a series of negative and positive deflections obtained from lateral electrode sites that is also sensitive to the acoustic properties of a stimulus (Näätänen and Picton, 1987; Wolpaw and Perry, 1975). These deflections are best observed from lateral temporal electrode sites because their main sources have a radial orientation (Näätänen and Picton, 1987; Tonnquist-Uhlen et al., 2003; Wolpaw and Perry, 1975). Source analyses based on non-invasive recordings have been confirmed through intracranial recordings obtained directly from the lateral superior temporal gyrus (Howard et al., 2000; Steinschneider et al., 2011a, 2011b). Attenuated T-complex measures serve as markers of language impairment, suggesting that the underlying sources may play a role in language development and processing (Shafer et al., 2011; Tonnquist-Uhlen, 1996).

1.1. Language experience

Physiological investigations of native-language speech perception have revealed that experience with the phonological patterns of one's native-language influences relatively late stages of neural processing (Dehaene-Lambertz et al., 2000; Näätänen et al., 1997; Sharma and Dorman, 2000; Wagner et al., 2012). However, it is unclear whether experience with the phonological patterns of a listener's native-language influences earlier stages of cortical speech processing.

Research investigating this question has been equivocal. Several studies examining obligatory AEPs recorded from midline sites and elicited by syllables varying in their voice onset time (VOT) have shown no effect of listeners' native-language experience (Elangovan and Stuart, 2011; Sharma and Dorman, 2000). In contrast, Zhang et al. (2005) using magnetoencephalography (MEG) found two N1m peaks to the syllable /la/ for Japanese, but not American listeners and argued that only the American listeners showed integration of the features of the phoneme /l/.

Brief exposure to sounds during psychoacoustic training (e.g., a VOT non-native sound contrast) modulates the frontocentral N1 and P2 waves (for review Kujala and Näätänen, 2010; Reinke et al., 2003; Tremblay et al., 2001; Tremblay and Kraus, 2002), suggesting a change related to speech perception. Also, P2 may reflect sensory mechanisms that lead to conscious perception (Ceponiene et al., 2005, 2008, 2009; Tremblay and Kraus, 2002). For example, Ceponiene et al. (2005) suggested that P2 reflects a transition between acoustic feature detection and integrated sensory processing through facilitating or inhibiting

conscious perception of speech (Ceponiene et al., 2005, 2008, 2009). In the current study, we take advantage of the fact that adult listeners have a lifetime of exposure to native-language sound contrasts. If neural generators contributing to the frontocentral P2 wave facilitate or inhibit conscious perception of speech, then a language groups' ability to perceive (or not perceive) a sound contrast should affect P2.

Further, the T-complex has been shown to reflect features of linguistic processing (Friedrich et al., 2009; Shafer et al., 2011, see also Chang et al., 2010). Therefore, we concurrently examined the effect of acoustic (physical) and phonological (meaningful in a language) contrasts within natural nonsense word stimuli on the P1–N1–P2 and T-complex responses.

1.2. Overview

The current research was part of a larger project that examined the effects of phoneme context on speech perception utilizing the consonant cluster /pt/ that occurs in English in word offset (e.g., “except”), but not in word onset. In contrast, native-Polish listeners experience the /pt/ cluster in their language in both word onset and offset.

Perception of /pt/ was explored using the word onset sequences /pt/ and /p t/ in nonsense word stimuli. These sequences are linguistically contrastive in word onset in Polish (e.g., Polish: “ptak” translated as bird, “Petronella” - a name), but not in English (e.g., English: “petunia”). The phoneme sequences /st/ and /s t/ were used as experimental controls because both languages contrast these sequences in word onset (e.g., Polish: “stal” translated as steel, “suterena” translated as basement; English: “stay”, “sateen”). Fig. 1 shows acoustic waveforms for specific productions of the naturally recorded stimuli.

Participants heard same and different nonsense word pairs (e.g., /p tima-p tima/, /p tima-ptima/ “peteema-pteema”) and determined whether the second word in the pairs had two or three syllables. Polish listeners were able to distinguish the 2 and 3-syllable nonsense words that began with /pt/ or /p t/, but English listeners were not (see Wagner et al., 2012).

Currently, we examine the P1–N1–P2 and T-complex responses to the first word in the word pairs to determine whether native-language experience is reflected within early sensory-obligatory components. We hypothesized that native-language patterns of speech perception would not be reflected at the early stages of cortical processing indexed by the P1–N1–P2 complex (Elangovan and Stuart, 2011; Sharma and Dorman, 2000), but might be observed within the T-complex whose main sources lie over non-primary auditory cortex.

2. Results

2.1. P1–N1–P2 complex

The P1–N1–P2 waveforms measured at fronto-central sites were highly similar between English and Polish listeners for both the 2 and 3-syllable *st* words and the 2 and 3-syllable *pt* words (Fig. 2). This similarity occurred even though these same English participants could not distinguish the /pt/versus /p t/ word onset contrasts (Wagner et al., 2012). Thus, acoustic features of the phoneme sequence onsets were registered by the P1–N1–P2, irrespective of native-language experience.

Dominance of acoustic feature processing can be further demonstrated by comparing waveforms to the words having fricative onsets relative to stop-consonant onsets. Brackets in Fig. 2 illustrate that waveforms for the /st/ and /s t/ onsets diverged for approximately 100 ms longer (232–472 ms) than waveforms for the /pt/ and /p t/ onsets (232–376 ms) for both the Polish and English listeners (Table 1). Thus, sensory processing for the /st/ and /s t/ onsets was longer in duration than for the /pt/ and /p t/ onsets, which corresponds to the

acoustics of the fricative onsets being 100 ms longer in duration than the stop-consonant onsets (see Fig. 1; also see Wagner et al., 2012). Thus, temporal processing of the /pt/ and /p t/ phoneme sequences was reflected within the P1–N1–P2 complex for the English listeners, even though these individuals were unable to behaviorally distinguish the sequences.

While the overall profile of the signature waveforms elicited by the 2 and 3-syllables were comparable between English and Polish listeners, later and slower components of the AEPs do diverge between the two language groups. AEPs recorded from Polish listeners were, in general, more negative for all conditions relative to the English listeners, suggesting processing differences between the two language groups. This finding is illustrated in Fig. 2, which shows that the waveforms elicited by /st/ and /s t/ became more negative for the Polish group beginning at 280 ms (280 through 496 ms: $F(1, 22)=9.99$; $p=.005$; partial eta squared=.312) and waveforms elicited by /pt/ and /p t/ became more negative for the Polish group beginning at 88ms (88 through 256 ms: $F(1, 22)=4.876$; $p=.038$; partial eta squared=.181; 280 through 496 ms: $F(1, 22)=10.726$; $p=.003$; partial eta squared=.328).

2.2. T-complex

As for the P1–N1–P2 complex, the acoustic distinctions within the *st* and *pt* 2 and 3-syllable words were reflected within the T-complex. Table 1 illustrates that temporal distinctions in the acoustic contrasts (i.e., /st/s t/ and /pt/p t/) reflected in the fronto-central P1–N1–P2 complex were similarly reflected in the T-complex from bilateral posterior temporal sites.

Also, T-complex waveforms for the /pt/ and /p t/ onsets diverged at the same time intervals for English and Polish listeners. Thus, neural networks underlying the T-complex were sensitive to the acoustic distinctions within the /pt/ and /p t/ onsets for both native and non-native listeners.

In contrast to the P1–N1–P2 complex, the T-complex from bilateral posterior temporal sites during the same time period showed a language effect specific to the 2-syllable /pt/ words, the legal word form in Polish, but illegal in English. Analysis of the T-complex revealed that the Polish listeners showed a more negative T-complex to the 2-syllable *pt* words relative to the 3-syllable words between 40 and 256 ms ($F(1, 22)=8.516$; $p=.008$; partial eta squared=.28) at bilateral posterior temporal sites (Fig. 3).

3. Discussion

3.1. P1–N1–P2 complex

The current research revealed that native-language phonotactic patterns were not reflected within the P1–N1–P2 complex, but rather responses were dominated by acoustic contrasts in a non-language specific manner. The 2 and 3-syllable *pt* words contain the word onset /pt-p t/ contrast that is a linguistic contrast in the Polish language, but not in the English language, and yet, the P1–N1–P2 signature waveforms differentiated the 2 and 3-syllable *pt* words for both the English and Polish listeners in the same manner. The current study supports research that has shown the P1–N1–P2 complex to primarily reflect acoustic, but not phonological aspects of the speech stimuli (Elangovan and Stuart, 2011; Sharma and Dorman, 2000). Contrasting results demonstrating different N1m responses by Japanese and English listeners may reflect particular feature processing for the /l/ phoneme or may reflect differences in experimental design that affect attention (Zhang et al., 2005).

Previous research suggests that the P2 obligatory AEP is sensitive to auditory experience (Tremblay et al., 2001; Tremblay and Kraus, 2002; Sheehan et al., 2005; Reinke et al., 2003). Exposure to one's native-language provides the ultimate practice of a skill, speech

perception of native-language contrasts. Why, then, does the Polish group not demonstrate a different P1–N1–P2 response to the 2-syllable /pt/ words?

Tremblay and Kraus (2002) suggested that the increased P2 response subsequent to training a non-native VOT distinction could have reflected the learning process because post-training modifications in behavioral perception and amplitude values were not correlated for individual subjects. This view is further supported by Atienza et al. (2004), who demonstrated an increased MMN subsequent to training a frequency deviation within a tone sequence; ERPs collected post training revealed a slow positive wave overlapping the P2 response attributed to new learning. The Polish listeners had highly established native-language sound patterns and P2 modifications attributed to new learning would not have been expected. Thus, the current results are consistent with the view that P2 modifications following non-native sound contrast training reflect processes involved in new learning, but not phonological perception.

The Polish listeners' P1–N1–P2 complex showed an enhanced negativity for all four of the word types. This enhanced negativity may suggest that the Polish group engaged greater resources of attention (Näätänen, 1990; Näätänen et al., 2011) during the experiment relative to the English listeners. It is possible that these Polish participants, who learned English as young adults (i.e., late bilinguals), listened more carefully to all stimuli because they recognized the speaker as an early bilingual. It is equally possible that this group of Polish participants was more engaged in the syllable identification task because they recognized Polish language contrasts that are not present in English within the stimulus set. Future research will be necessary to determine the effects of attention on neural speech processing in bilingual and monolingual listeners.

The current results do not support the claim that P2 reflects modulation of access to speech perception or that the P2 reflects a pre-attentive alerting mechanism that contributes to improved phonological perception (Ceponiene et al., 2002, 2008, 2009; Tremblay and Kraus, 2002). Polish listeners' P2 responses to words having the /pt/ onset did not differ from the English listeners' responses despite years of experience with this onset cluster and its contrast sequence (i.e., /p t/). Ceponiene and colleagues' argue that the P2 peak indexes a transition between acoustic feature detection and integrated speech processing and implies a hierarchical serial network with neural generators underlying the P2 response to lead to neural processes contributing to speech perception. In contrast, our results support additional parallel acoustic and linguistic processing networks (Näätänen et al., 2011; Näätänen and Winkler, 1999; Davis and Zerlin, 1966) because early language-group differences in response to the 2 and 3-syllable *pt* words were found from lateral posterior temporal sites, but not fronto-central sites.

3.2. T-complex

An increased negativity recorded from bilateral posterior temporal sites was restricted to the Polish listeners and specific for the /pt/ onset cluster relative to its contrast sequence (i.e., /p t/). This negativity specific for the /pt/ onset cluster suggests increased sound analysis by the Polish listeners to a phoneme sequence that is present only in the Polish language (Katarzyna Dziubalska-Kolaczyk, personal communication, January 9, 2010; also see Wagner et al., 2012) and thus, suggests an effect of language experience. Interestingly, the T-complex has its main sources underlying bilateral posterior temporal cortex (Howard et al., 2000) and phonological distinctions have been mapped to this region through electrocorticographic recordings from the exposed lateral temporal cortex (Chang et al., 2010).

Language group differences would be expected at higher levels of speech processing. Previous research had shown that minimal phonological differences within words were reflected from lateral temporal electrode sites at later stages of cortical processing around 350ms (Friedrich et al., 2009). The current research suggests an even earlier effect, given the enhanced negativity seen in Polish listeners for the /pt/ onset cluster.

3.3. Auditory signatures waveforms

The P1–N1–P2 waveforms and the T-complex showed longer duration sensory processing for the 2 and 3-syllable *st* words relative to the 2 and 3-syllable *pt* words, consistent with the acoustic characteristics of the stimuli. However, the P1–N1–P2 waveforms for both the *pt* and *st* stimuli did not begin to diverge until 232 ms, subsequent to the N1 response, even though the contrasting vowel within the /pt-p t/ phoneme sequences began at approximately 26 ms and the contrasting vowel within the /st-s t/ sequences began at approximately 122 ms. Interestingly, within the same time frame from bilateral temporal sites, the /pt-p t/ contrast was differentiated by the Polish listeners, suggesting feature integration within underlying auditory-cortical networks.

3.4. Conclusion

Current findings suggest that the P1–N1–P2 and T-complex signature waveforms are sensitive to the acoustic characteristics of speech. In addition, the T-complex reflected language experience, suggesting that neural networks within nonprimary auditory cortex from bilateral posterior temporal brain regions may be involved in early stage linguistic processing. The timing of this activity supports the view that linguistic and acoustic processing of speech occurs in parallel, as well as hierarchical, serial networks.

4. Experimental procedures

4.1. Participants

Twelve native-English (8 female) adults between the ages of 24 and 35 (mean age=29) and 12 native-Polish (8 female) adults between the ages of 23 and 34 (mean=30) participated in the study. Native-Polish listeners were bilingual speakers who had learned English as young adults, after the age of 15 years. The English listeners reported having no experience with Polish or other Slavic languages. All participants demonstrated normal hearing and were without a history of speech, language or cognitive impairment.

4.2. Stimuli

Stimuli consisted of 800 same and different nonsense word pairs. Nonsense words began with /pt/, /p t/, /st/ and /s t/ and were potential real words in the Polish and English languages with the exception of nonsense words that began with /pt/, an illegal phonotactic form in English. Phoneme sequences that followed the /pt/, /p t/, /st/ and /s t/ onsets in the words varied and words in the *pt* and *st* conditions were matched for rhyme (e.g., /pt sa/, /p t sa/, /st sa/, /s t sa/). Each word type (e.g., /st/words) consisted of 2 natural productions of 50 nonsense words (e.g., /stIna/). These 100 natural productions were presented twice within the experiment, once within a same pair and once within a different pair for a total of 200 trials per word type. Stimuli were produced by a male native-Polish speaker who emigrated from Poland to the United States with his family at age 6 years. The speaker learned English in school, but continued to converse only in Polish at home. The Polish participants described the speaker as having good Polish pronunciation. He spoke English without a Polish accent.

Stimuli were presented through speakers in a sound-treated electrically shielded room using E-prime (Version 1.1) software. Word pairs were presented with a 2 s inter-trial interval

(ITI) and 250ms inter-stimulus interval (ISI). Procedures were identical to those reported in Wagner et al. (2012) with the exception that, for the current study, ERP epochs time-locked to the first word in the word pairs were analyzed.

4.3. EEG acquisition and analysis

A 65 channel net was used for data collection (Electrical Geodesic Inc.). Prior to testing, we confirmed that impedance levels were at or below 40 kOhms, an acceptable level for the high-impedance amplifiers used (Ferree et al., 2001). The EEG was recorded at a sampling rate of 250 Hz, bandpass filtered between .1 and 30 Hz and referenced to Cz. Net station software (Version 4.1.2) was used for data processing (i.e., segmentation, artifact rejection, averaging, baseline correction). The continuous EEG wave was segmented into an 1800 ms segment, which consisted of a 200ms baseline and a 1600ms post word onset segment. Data was baseline corrected between –100 ms and 0ms and re-referenced to an average reference.

The P1–N1–P2 complex was obtained from fronto-central site 4, left fronto-central site 5, site 65 (Cz) and right fronto-central site 55. The T-complex was obtained from left-anterior temporal site 20, right-anterior temporal site 56, left-posterior temporal site 24 and right-posterior temporal site 52 (see Wagner et al., 2012).

The mean number of epochs averaged (and range) for each participant group and word type follows. For the Polish participants: a mean of 161 epochs (range 68–197) was averaged for the /pt/ word type, 162 epochs (range 69–194) for the /p t/ word type, 158 (range 67–200) for the /st/ word type and 158 epochs (range 59–195) for the /s t/ word type. For the English participants: a mean of 166 epochs (range 82–193) were averaged for the /pt/ word type, 166 epochs (range 101–197) for the /p t/ word type, 166 (range 88–192) for the /st/ word type and 167 epochs (range 83–200) for the /s t/ word type. Raw voltage amplitudes were averaged across 24 ms time intervals for statistical analysis. A mixed ANOVA with group (12 native-English and 12 native-Polish participants) as the between subject factor and condition (2 or 3-syllable word forms), time and site as the within subject factors was used. Greenhouse-Geisser correction was applied when appropriate and Tukey's HSD was used for post hoc testing ($p < .05$). Main effects of condition and language group and significant interactions involving condition were reported.

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Sample Acoustic Waveforms for the Four Word Types

Fig. 1.

Acoustic waveforms for specific productions of the naturally recorded stimuli. Total word durations in parentheses follow each word label. A vertical line within each waveform corresponds to initial segment durations from word onset through the burst for /t/ illustrating the longer durations for words containing fricative onsets relative to stop-consonant onsets.

P1-N1-P2 complex with standard error of the mean (SEM) 2 and 3-syllable words

Fig. 2.

The grand mean P1–N1–P2 waveforms and standard error of the mean (SEM) for 2 and 3-syllable *st* words (top) and *pt* words (bottom) for English (left) and Polish participants (right) at electrode site 4. Notice the similarity in the signature patterns for both groups and the more negative response by the Polish participants for all word forms. Brackets illustrate that 2 and 3-syllable waveforms diverge for a longer duration of approximately 100 ms for the *st* relative to the *pt* stimuli (see text). Positive=up.

T-complex with standard error of the mean (SEM)

Fig. 3.

The T-complex and standard error of the mean (SEM) to the 2 and 3-syllable *pt* word forms from left and right-posterior temporal sites for the English (top) and Polish (bottom) participants. Notice the increased negativity to the 2-syllable *pt* word forms relative to the 3-syllable word forms only by the Polish listeners. Positive=up.

Table 1

Waveform amplitude values differ significantly for the 2 and 3-syllable word forms at similar time intervals at fronto-central and bilateral posterior temporal sites for the (a) *st* conditions and (b) *pt* conditions.

P1-N1-P2	T-complex LA	T-complex LP and RP
(a)		
232 ms *	232 ms	232 ms *
256 ms *	256 ms	256 ms *
280 ms *	280 ms	280 ms *
304 ms	304 ms	304 ms
328 ms *	328 ms	328 ms *
352 ms *	352 ms *	352 ms *
376 ms	376 ms *	376 ms
400 ms *	400 ms	400 ms
424 ms *	424 ms	424 ms *
448 ms *	448 ms	448 ms *
(b)		
232 ms *	232 ms *	232 ms
256 ms *	256 ms *	256 ms *
280 ms	280 ms	280 ms
304 ms *	304 ms	304 ms *
328 ms *	328 ms	328 ms *
352 ms *	352 ms	352 ms *

Asterisk * = $p < .05$ Tukey HSD.