Perception of Japanese vowel duration contrasts by L1 and L2 learners of Japanese: An EEG study.

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Abstract

One challenge of second language (L2) acquisition research is to evaluate to what extent experience with an L2 leads to changes in automaticity of L2 speech perception. The present study investigated neural indices of speech processing using electroencephalography (EEG). The Mismatch Negativity (MMN) event-related potential (ERP) served as an index of speech discrimination of a Japanese vowel duration contrast (tado-taado), which is phonemic in Japanese (JP), but not English. Native speakers of Japanese (JPN), naïve American English (AEN) listeners (i.e., no knowledge of JP), and one semester college course L2 learners of JP (JPL2) were tested to determine whether experience with JP leads to changes in discrimination of the target contrast at a pre-attentive level of processing. EEG responses were recorded to natural exemplars of *tado* and *taado* while listeners performed an unrelated visual attention task that drew attention away from the auditory stimuli. JPL2 showed a larger amplitude MMN than AEN listeners, but a smaller amplitude MMN than JPN listeners. This study suggests as little as one semester classroom experience with the L2 (JP) enhances discrimination of an L2 phonemic contrast not found in the first language (L1), but L2 speech processing is still less robust (or less automatic) than for L1 listeners.

Keywords: Event-related potentials (ERPs); Mismatch Negativity (MMN); Japanese temporal-cues; Attention; Discrimination; Speech Perception

Introduction

Studies of second language (L2) learning have firmly established that late (adult) learners of an L2 generally show poorer perception and production of L2 phonological contrasts not found in the first language (L1) compared to early (child) L2 learners, even after considerable experience with the language and attaining high proficiency on some language measures (e.g., comprehension) (e.g., Levy & Strange, 2008). The limitations on L2 phonological learning at a late age may be due to a critical/sensitive period for language learning (e.g., Knudsen, 2004), to less experience with the L2 (Flege, 2003), to interference from the L1 (Iverson et al., 2003), or some combination of these three factors. Improvements in L2 speech perception do occur over time, but more so for some learners than others. Most studies focusing on adult L2 learning have examined and shown the amount of experience with an L2 results in improvements in L2 phonology, but rarely to a native-like level (e.g., Flege, 2003). A few studies have also suggested that some L2 learners have intrinsic (genetic) abilities that make them superior L2 learners (Bishop et al., 1996). An understanding of the nature of changes in L2 speech perception relative to the amount of experience versus intrinsic abilities can shed light on why native-like speech perception and production are rarely achieved.

A major difference in L1 and L2 speech perception is automaticity (Shafer & Strange, 2008; Strange, 2011). Listeners are highly automatic in discriminating and categorizing L1 speech sounds, which allows for robust processing of native-language speech even under difficult listening conditions (e.g., noise) or in tasks requiring high cognitive load (Strange, 2011). In contrast, late L2 learners typically require additional cognitive (e.g., attentional) resources for good speech perception of L2 speech sounds that are not contrastive in the L1. It is likely that L2 learners rely on their L1 selective perception routines (SPRs) under difficult conditions because these L1 routines are automatic. Thus, even for highly proficient L2 learners, L2 speech perception may be poor in complex tasks and under less-than-optimal listening conditions which are common in communicative situations (Bradlow & Alexander, 2007).

A critical theoretical question is whether L2 learning in adults can ever reach a comparable level of automaticity to L1 speech perception. Evidence that automaticity can be achieved past puberty (often suggested as the upper bound for the critical period), would suggest that there are external (i.e., experiential) rather than internal (i.e., brain maturation) constraints on learning (Shafer et al., 2011).

One challenge is to measure to what extent experience with an L2 leads to changes in perception of L2 speech sounds at a behavioral level, but also in terms of automaticity of processing these sounds. Neurophysiological measures are ideal for examining speech perception at early levels of processing that reflect automaticity, and index the brain mechanisms that support L1 versus L2 speech perception.

MMN index of discrimination. Mismatch negativity (MMN) (Näätänen et al., 2007), an Event Related Potential (ERP) measure, is an increased negativity to an infrequent stimulus (deviant) against the background of a frequent stimulus or pattern (standard). MMN is believed to index short-term representations of patterns of sound in the auditory system, and is sensitive to auditory salience with smaller acoustic differences showing decreased and delayed peak. However, the status of a speech contrast in a listener’s L1 may also affect the amplitude and/or latency of MMN (e.g., Dehaene-Lambertz et al., 2000; Menning et al., 2002; Nenonen et al., 2003; 2005; Shafer et al., 2004; Näätänen et al., 2007), for contrasts differing in spectral cues (e.g., Winkler et al., 2003) and duration cues (e.g., Menning et al., 2002; Nenonen et al., 2003; Hisagi, Shafer, Strange & Sussman, 2010).

MMN provides an index of the robustness of auditory representations at a more automatic level of processing, when attention is directed away to another modality (Näätänen, 1990; Shafer et al., 2005; Hisagi et al., 2010). For some stimulus contrasts, the MMN is larger when attention is directed to the contrast, compared to away from it (Gomes et al., 1999). This increase in amplitude is indicative of strengthening of the auditory representation of the sound pattern at early stages of cortical processing (Sussman, 2007). Highly automatic perceptual processes require robust (salient) neural representations (Crick and Kock, 1990).

Weak neural representations can be strengthened through the process of learning. However, there may be age constraints on plasticity for some cortical regions for sensory learning (Lenneberg, 1967; Knudsen, 2004); in neural circuits constrained by such critical/sensitive periods, learning, although possible, would require a rich environment or considerable "energy" (Knudsen, 2004). We suggest that the process of over-learning L1 speech contrasts leads to the development of highly salient neural representations in auditory cortex (e.g., Hisagi et al., 2010; Shafer et al., 2011). Crucially, when attention is directed away from the auditory modality, MMN reflects discrimination at a pre-attentive, automatic level of processing. Thus, this measure serves as an excellent index of automaticity of speech perception in an L2. Our recent study (Hisagi et al., 2010) clearly demonstrated that Japanese (JP) listeners show equally robust MMNs to native JP duration contrasts, whether attention is directed towards or away (by means of a visual task) from the auditory modality. In contrast, American English (AE) listeners only showed robust MMNs when attention was directed towards these non-native vowel-duration differences. This study strongly supports the interpretation that measures of MMN (presence, amplitude/latency) can be used to evaluate the automaticity of discrimination of acoustic-phonetic cues for phonemic contrasts.

A few studies have addressed whether L2 learning leads to changes in pre-attentive speech perception as measured by the MMN. Some studies show that training leads to increased MMN amplitude (e.g., Peltola et al., 2005; Ylinen et al., 2010), and that the left hemisphere plays a special role (e.g., Zhang et al. 2009). However, other studies suggest little improvement in L2 speech perception as a result of classroom immersion (e.g., Peltola et al., 2003; 2007). These studies used a passive task, where attention was not controlled, which could contribute to the different results.

The current study examined whether AE L2 learners of Japanese (JPL2) show changes in speech discrimination of a JP contrast at a pre-attentive level using the MMN component. The task from Hisagi et al. (2010), in which attention was directed away from the auditory stimuli (visual attend task), was used to examine discrimination at a pre-attentive level. We predicted that JPL2 learners would show larger MMN amplitude to the JP vowel contrast compared to naïve AE listeners (AEN) after one semester of classroom experience, but that the MMN amplitude might still be weaker than for native JP listeners (JPN).

2. Material and Methods:

Overall material and methods are the same as in (Hisagi et al., 2010) (and further details in Hisagi, 2007). The JP nonsense words /taado/ with a long vowel /aa/ served as the standard stimulus, and /tado/ with a short vowel /a/ as the deviant stimulus. Four naturally-produced tokens of each category (long and short) were recorded and used to encourage discrimination on the basis of the phonological difference (vowel duration) rather than irrelevant acoustic-phonetic differences that occur between any pair of naturally-produced speech forms. The average duration ratio of the long to short target vowels (/aa/ in /taado/ vs. /a/ in /tado/) was 1.61, with durations of individual tokens varying from 83 to 88 ms for /a/ (mean: 86 ms) and from 128 to 148 ms for /aa/ (mean: 138 ms). The mean ratio of long versus short total word duration (from onset of /t/ to offset of /o/) was 1.21. The mean for /tado/ was 206 ms (range: 202–214 ms) and for /taado/ was 250 ms (range: 237–264 ms).

For visual stimuli, we used four different sizes of pentagon and hexagon shapes (orange with black background) to construct the oddball visual discrimination test. The probability of standards versus deviants was 85% versus 15% for both the auditory and visual stimuli. The inter-stimulus interval was 800 ms for the auditory and 780 ms for the visual stimuli. Participants were asked to attend to the visual stimuli and count the deviant visual shapes (hexagons) and report the number at the end of each block. Participants received 14 blocks (average: 100 trials per block with a different number of standards and deviants) for a total of 1190 standard and 210 deviants.

Data were collected at The Graduate Center, City University of New York (CUNY), and at the Athinoula A. Martinos Imaging Center at the McGovern Institute for Brain Research at Massachusetts Institute of Technology (MIT), as is described below.

2.1 Participants

Control groups: 12 native speakers of Japanese (JPN) (10 females; between 23-37 years) and 12 native speakers of American English (AEN) (8 females; between 23-40 years) were tested at CUNY. We also tested 6 native speakers of American English (6 females; between 18-22 years) at MIT to calibrate the data on the two different EEG systems (see Figure 1).
Experimental group: 12 native speakers of AE (JPL2) (between 18 and 25 years), who had studied one semester of Japanese, were tested at MIT on an EEG/MEG simultaneous system.
Electroencephalography (EEG) Recording: For CUNY data, see Hisagi et al. (2010). For MIT data, simultaneous MEG (306-channel) and EEG (60-channel for L2 subjects and 74-channel for control subjects[1]) measurements were recorded using the Elekta Triux system, which offers accurate estimates of auditory evoked responses and their cortical representations (Sharon et al., 2007). Data were recorded with sampling rate 1000 Hz and then downsampled to 250 Hz to match the CUNY data.

2.2 Analysis

The current paper focuses on the EEG data because MEG data was no available from the CUNY study. Data was processed offline using the BrainStorm software (Tadel et al., 2011) to extract ERP responses. We conducted multiple repeated measures ANOVA on the ERP responses, using data from 6 electrodes: F3, FZ, F4, C3, CZ, and C4, which sampled frontal and central sites, and both hemispheres. Depending of the effect of interest, we used different factors, including:

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[1] EEG caps were replaced from 60-channel to 74 channel in the middle of the study beyond our control.

between-subject factor the Group, and within-subject factors the Stimulus (standard, deviant), Site (frontal, central), Hemisphere (left, midline, right) and Time (six 40-ms intervals: 120–160; 160–200; 200–240; 240–280; 280–320; and 320–360 ms). MMN was expected to invert in polarity at the mastoids. Thus, to ascertain the presence of MMN, the left mastoid, right mastoid, or an average of the two mastoids were also selected for further analysis using Inversion as a main factor with MMN vs. mastoids. A significance level of 0.01 was used for analyses to minimize spurious findings. Hemisphere was included as a factor because previous research suggests that the greatest language-related differences might be seen at the left hemisphere (Näätänen, et al., 2007). Time was included to determine the temporal extent of the MMN. After establishing whether a Stimulus effect was significant for the three groups (deviant vs. standard), additional ANOVAs using subtraction waveforms (deviant–standard) were undertaken to directly compare the MMN between groups and included Site, Hemisphere and Time, where appropriate. A significance level of 0.05 was used for these comparisons because they directly test the questions of interest.

3. Results

Comparison of the MMN for the AE participants collected at CUNY and MIT revealed remarkably similar latency and amplitude for the MMN (Figure 1). T-tests comparing the subtraction wave (deviant–standard) showed no significant difference (p = range 0.07~0.95). Thus, the AEN MIT participants showed a relatively small MMN, similar to the AEN CUNY group.

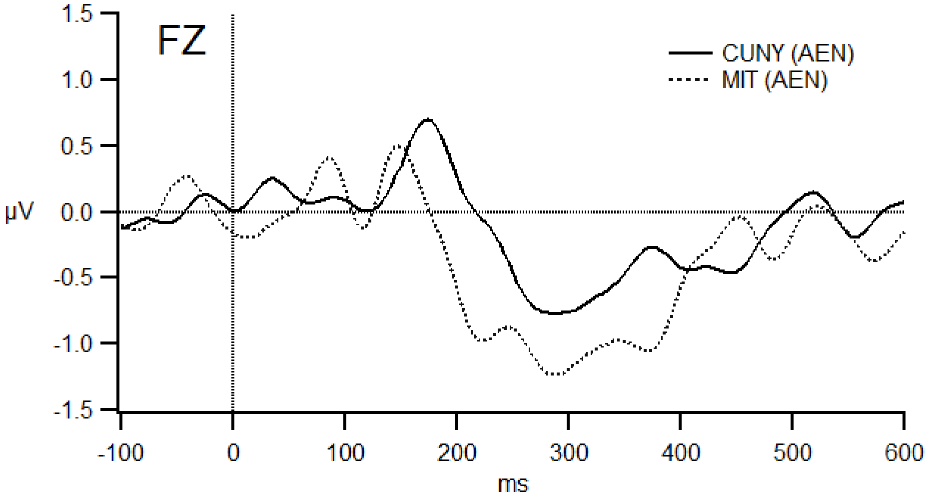

Figure 1. MMN waveforms at electrode FZ for the AEN group. Participants tested at CUNY (solid line) and MIT (dotted line) produced similar waveforms, indicating that data across EEG systems are directly comparable. Positive is plotted up

First, a five-way ANOVA was conducted to determine whether MMN was significantly present. The analysis showed many significant effects, including a main effect of Group [F (2, 33) = 3.31, p = 0.05], Stimulus [F (1, 33) = 15.69, p = 0.000) and an interaction of Stimulus x Time x Group [F (10, 165) = 8.11, p = 0.000]. The three groups were then examined separately to identify whether a stimulus effect (indicating discrimination) was present for each. JPN group had a significant main effect of Stimulus [F (1, 11) = 15.23, p = 0.002] and an interaction of Stimulus x Time [F (5, 55) = 43.31, p = 0.000]. The AEN group had no main effect of Stimulus [F (1, 11) = 0.51, p = 0.489], but an interaction of Stimulus x Time [F (5, 55) = 10.40, p = 0.000]. The JPL2 group had a main effect of Stimulus [F (1, 11) = 8.92, p= 0.012] and an interaction of Stimulus x Time [F (5, 55) = 11.66, p = 0.000]. In general, for all language groups, a greater negativity was found for the deviant compared to the standard.

Next, we conducted further analyses using the subtraction waves to study the group interaction. Significant interactions of Group x Time [F (10, 165) =7.89, p = 0.000], Group x Hemisphere x Time [F (20, 330) =3.75, p = 0.000], and Group x Site x Hemisphere x Time [F (20, 330) =1.97, p = 0.008] were observed. To follow up the interaction, each hemisphere was analyzed separately. All the hemispheres showed a significant interaction of Group x Time: Left hemisphere (F3 and C3) [F (10, 165) = 5.97, p = 0.000]; Midline sites (FZ and CZ) [F (10, 165) = 8.50, p = 0.000]; Right hemisphere (F4 and C4) [F (10, 165) = 5.63, p = 0.000].

In Figure 2, group mean subtraction waveforms (FZ and F3) are shown for the groups of 12 JPN, 12 AEN and 12 JPL2. The JPN group showed larger MMN than that of AEN and JPL2 groups in the last three time intervals (i.e., 240 to 360ms). 10 out of 12 JPN listeners showed robust MMNs but only 4 of 12 AEN listeners (Hisagi et al., 2010). 9 out of 12 JPL2 learners showed MMNs larger than -0.5 µV, but not generally of less magnitude than the JPN listeners.

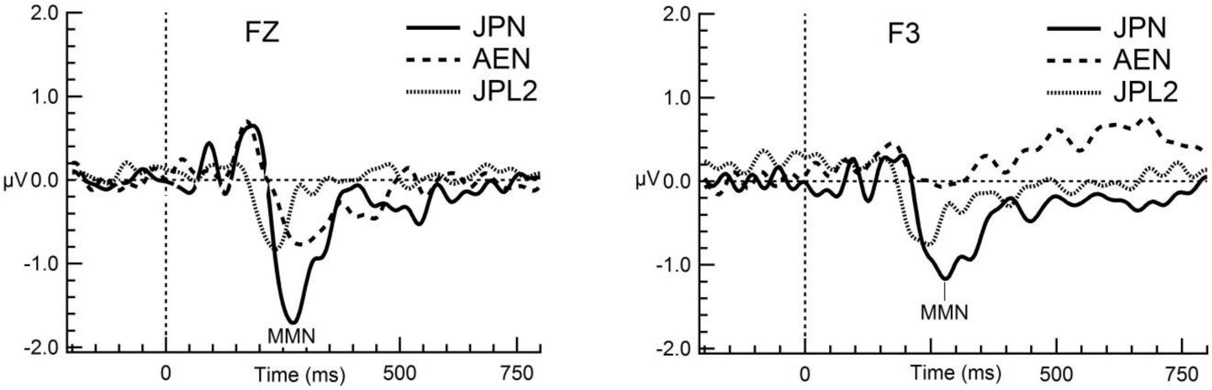

Figure 2. MMN waveforms at FZ (midline) and F3 (left frontal) for JPN, AEN, and JPL2. The MMN at FZ is larger for JPN group than AEN and JPL2 groups. The MMN shows clear modulation among the three groups at F3 (JPN > JPL2 > AEN).

To follow up further, each group was also analyzed separately. All groups showed significant interactions of Hemisphere x Time: JPN [F (10, 110) = 2.63, p= 0.007]; AEN [F (10, 110) = 5.73, p= 0.000]; JPL2 [F (10, 110) = 2.00, p= 0.039]. In addition, the JPN and AEN groups showed interactions of Site x Hemisphere x Time: JPN [F (10, 110) = 3.06, p = 0.002]; AEN [F (10, 110) = 3.28, p = 0.000]. Post-hoc analysis of the two-way interactions of Hemisphere and Time, revealed that the MMN was larger over midline and left sites than right sites. Post-hoc tests revealed that the JPN group showed a significant difference in the 240-280 ms interval between the midline (FZ) and right site (F4) ($p < 0.05$), with amplitude greatest at the midline. The post-hoc pairwise comparisons did not reveal significant hemisphere difference for any time interval for the AEN or the JPL2 group.

Lastly, the analysis with mastoids was conducted to ascertain the presence of MMN. It showed a significant main effect of Inversion [F (1, 33) = 11.00, p = 0.002], and interactions of Inversion x Time [F (5, 165) = 43.094, p = 0.000], Inversion x Time x Group [F(10, 165) = 6.756, p = 0.000], Inversion x Time x Hemisphere [F (10, 330) = 2.877, p = 0.002], and Inversion x Time x Hemisphere x Group [F (20, 330) = 1.85 p = 0.02]. This was followed up with a separate analysis per group. All three groups showed interactions of Inversion x Time (JPN: [F (5, 55) = 35.44, p = 0.000]; AEN [F (5, 55) = 9.68, p = 0.000]; JPL2: [F (5, 55) = 11.51, p = 0.000)]). In addition, the JPN group showed a significant main effect of Inversion [F (1, 11) = 12.20, p = 0.005], and interactions of Hemisphere x Time [F (10, 110) = 2.84, p = 0.004] and Hemisphere x Time x Inversion [F (10, 110) = 3.40, p = 0.000]. The AEN group also showed interactions of Time x Hemisphere [F (10, 110) = 6.53, p = 0.000]. Figure 3 shows the results of the three way interaction, which clearly illustrate the greater positivity at the mastoids for the JPN group in the later time intervals.

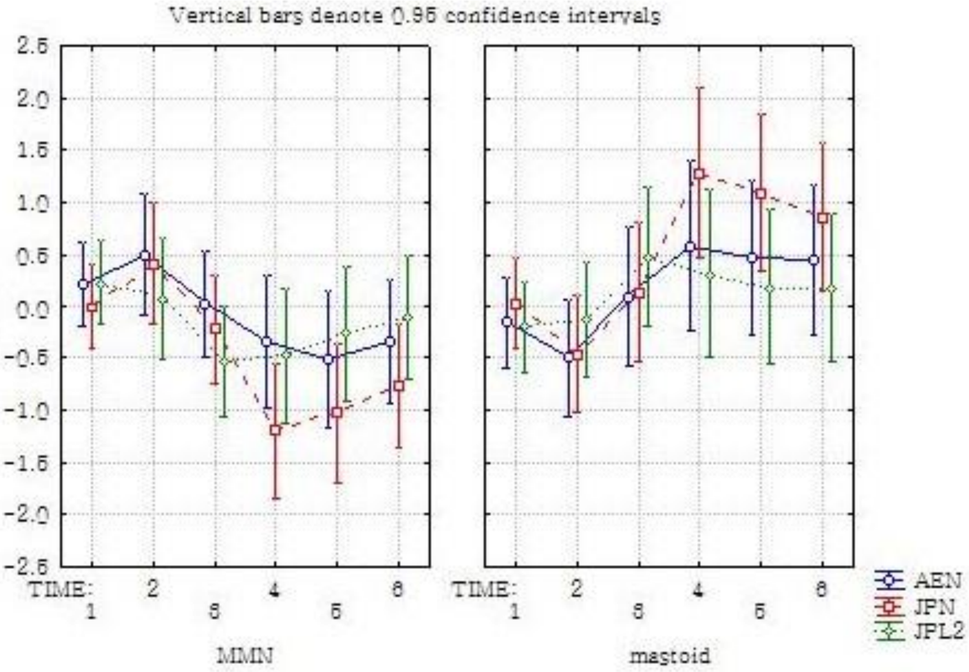

Figure 3. Three-way Inversion interactions among the three groups. The greatest positivity is shown at the mastoids for the JPN group in the later time intervals.

4. Discussion and Conclusion

In this study, we examined elementary JPL2 learners (one semester of Japanese) to determine the following: 1) the level of automaticity (indexed by MMN amplitudes and latencies without focused attention) once they have some JP knowledge, and 2) whether some JPL2 learners can achieve native-like automaticity. We found that 1) JPL2 learners showed stronger MMN than AEN speakers, but still not as strong as that of JPN speakers, and 2) the frontal left hemisphere (electrode F3) showed a clear difference among the three groups (size of MMN: JPN > JPL2 > AEN). Similarly, Näätänen et al. (2007) observed the greatest language-related differences over left hemisphere sites. Thus, experience with an L2 appears to change processing in auditory cortex to L2 speech sounds, particularly in the left hemisphere. This phenomenon suggests a tight relationship between the left hemisphere and automaticity in L2 speech perception. Given this result, increased MMN amplitudes to L2 speech in left hemisphere could be used as an indicator of L2 phonological learning.

Our study revealed that L2 language experience (via classroom learning) leads to changes in speech perception at attention-dependent (behavioral) and attention-independent (ERP) levels of processing of phonemic duration contrasts found in the L2, but not the L1. Following only one semester, we can see changes in processing L2 contrasts. The training studies by Peltora et al. (2005) and Ylinen et al. (2010) showed some improvement similar to our study; however, other studies of classroom immersion experience showed little improvement (Peltora et al., 2003, 2007), despite the fact that the L2 students were advanced (Peltora et al., 2003) or received early language immersion (Peltora et al., 2007). It is possible that difference in task (lack of attention control) and/or stimuli (synthetic vowel stimuli instead of natural tokens) can account for less evidence of improvement in L2 discrimination at the level of MMN.

In the current study, all JPL2 learners had teachers who were native speakers of Japanese and the class met four hours per week. This study suggests that quality experience with the L2 for at least four hours per week leads to increased robustness of discrimination of L2 phonemic contrasts, indexed by increased negativity over frontal sites; however, these L2 representations (or SPRs) are still less robust than those of L1 listeners, as indexed by smaller MMNs over central sites. Even with the limited focus in the classroom situation, the students improved L2 speech perception skill. This finding may be limited to vowel duration cues because vowel duration serves as a secondary cue for English listeners (short versus long vowels) and thus may be easier to learn than other L2 phonological differences (Bohn and Flege, 1990).

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