BALANCED BILINGUALS HAVE ONE INTERTWINED PHONOLOGICAL SYSTEM

Maija S. Peltola, Henna Tamminen, Heidi Lehtola and Olli Aaltonen

Department of Phonetics and the Centre for Cognitive Neuroscience, University of Turku, Finland
maija.peltola@utu.fi, henna.tamminen@utu.fi, heidi.lehtola@utu.fi, olli.aaltonen@utu.fi

ABSTRACT

Speech sound perception is based on automatically responding neural memory traces. In order to see, whether balanced bilinguals have two separate phonological systems, which can be activated in accordance with the linguistic context, we performed discrimination tasks and recorded the mismatch negativity (MMN) response from 12 Finnish-Swedish bilinguals in both linguistic contexts. Our results suggest that vowels are perceived by an intertwined phonological system, which includes the representations for the phonological categories of both languages. This system is triggered equally efficiently by both languages.

Keywords: perception, bilingualism, context language, discrimination, mismatch negativity

1. INTRODUCTION

Speech sound perception is based on the functioning of automatically responding long-term memory traces, which are language-specific in nature [10]. Early exposure to a non-native language [13] as well as extensive authentic input during adulthood [18] may also result in the formation of new language-specific representations. The memory traces revealed by the mismatch negativity (MMN) component of the event-related brain potential [9] are a concrete realization of the manner in which the brain is organized according to the phonological system of either monolinguals or bilinguals.

The vague term *bilingualism* may relate either to the timing of acquisition of the two languages (simultaneous or consecutive), or the obtained level of competence [3,4]. The findings by Perani et al. [14,15] showed that fluent bilinguals (L2 learners) show similarly distributed neural activations for both languages while activations are separate in less fluent speakers. In a study by Hernandez et al [5], it was shown that the same cortical areas are activated by the two languages, but that switching from one language to another activates additional areas. Albert and Obler [2] suggest that the “input switch” responsible for the perception of the two languages is automatically tuned in for the characteristics of the incoming speech, which implies that there are two separate linguistic systems and each of them functions automatically in response to the linguistic context.

The question of whether bilinguals have one intertwined phonological system or two separate systems (which may or may not be automatically activated) can be studied by varying the linguistic context during the experimental series. Winker et al. [17] showed that the linguistic context had no effect on the MMN responses of bilingual subjects (fluent L2 learners), suggesting an intertwined phonological system. In contrast, Peltola and Aaltonen [11] showed that fluent L2 learners have two separate systems triggered by the context language. Altogether, taking into account that the L2 learners in Peltola and Aaltonen were classroom learners of L2, while the subjects in Winkler et al. were immigrants, the manner in which the second language is learned appears to be of significance.

The type of bilingualism where two languages are learned simultaneously from infancy resulting in a complete mastering of both languages, may tentatively be based on either two separate systems or one uniform system. Also, it may be that attention-demanding and preattentive tasks do not show this similarly, since even if memory traces are not automatically triggered in a native-like manner, it may be possible for bilinguals to perform according to the target language system in behavioral experiments [12].

2. EXPERIMENT 1: DISCRIMINATION

The ability to discriminate between speech sounds is not linear, but instead, the sensitivity is highest at the L1 category boundary and lowest near the prototypical exemplar (e.g. [8]). This may be caused either by the phoneme boundary effect, or the perceptual magnet effect, which may be reflections of the same perceptual phenomenon [6]. The reaction times (RT) are shorter and the d-prime (*d'*) values are higher in between category discrimination than in within category discrimination [1].

2.1. Procedure

We measured the discrimination sensitivity (button press) in bilinguals in different linguistic contexts in two sessions (min. a week apart; one language per session). The session started with an identification experiment (see [7] for details) on the basis of which the stimuli were selected for the following discrimination task and EEG-registration whose order was balanced.

2.1.1. Subjects and stimuli

Twelve right-handed (Edinburgh Handedness Inventory) Finnish-Swedish bilinguals (one parent – one language from infancy) participated in the experiment (7 females, age range 16-31, mean 20.3 years). All subjects had normal hearing according to prior testing.

The stimuli (N=18, synthesized using HLSyn software) were chosen on the basis of identification (ID) experiments covering the closed vowel continuum divided into two categories in Finnish (/y/-/u/) and three in Swedish (/y/-/ʉ/-/u/). The duration of the stimuli was 350 ms including a 30 ms amplitude ramp at the onset and offset. The F0 contour started from 112 Hz and reached the maximum (132 Hz) at 100 ms and ended at 92 Hz. The F1, F3 and F4 values were constant at 344 Mel, 1748 Mel and 2019 Mel, respectively, while F2 varied in steps of 50 Mels from 703 to 1553. On the basis of the ID-experiments, two pairs (2 x standard + deviant) of stimuli were then individually selected for each subject so that one pair crossed the phoneme boundary in Finnish, but not in Swedish, and vice versa, while the acoustic distance was always 100 Mel. The stimuli were presented (with Presentation software) via headphones (Sennheiser HD 25) in the oddball paradigm in two blocks, where the standard stimulus (N=130) was randomly replaced by an infrequent deviant (N=20; $p = 0.133$).

2.1.2. Analysis

The RT's were measured from the onset of the stimulus and button presses occurring within ±3 standard deviation were included in the analysis. The *d'* values were calculated according to the number of hits, misses, false alarms and correct rejections. The obtained values were then subjected to a 2 (context language) x 2 (phonological status, within/between) Repeated measures ANOVA.

2.2. Results

There are no systematic differences between the RTs and *d'* values when they are compared within a context language, i.e. the within and between category differences are non-existent (see Table 1). This was confirmed by the statistical analysis, which showed a non-significant effect of the phonological status of the stimulus pair (f(1,11)=0.104, p=0.754, n.s.). The role of the linguistic context does not seem to affect the RTs and *d'* values either: the statistical analysis revealed a non-significant effect of the context language (f(1,11)=0.616, p=0.449, n.s.). In addition, there was no interaction between the phonological status and the linguistic context (f(1,11)=0.354, p=0.564, n.s.). It seems that the discrimination is based on the same mechanism irrespective of whether the bilinguals are in a Finnish or Swedish speaking environment.

Table 1: The Reaction Times (RT) and d-prime (*d'*) values for Finnish and Swedish between category (btw) and within category (within) contrasts.

	Finnish	Swedish
RT btw	469.0	471.3
RT within	463.8	483.8
d' btw	4.356	4.446
d' within	4.499	4.337

3. EXPERIMENT 2: MMN

The mismatch negativity (MMN) event related potential is not only sensitive to acoustic differences, but seems to have a phonological component [19]. In contrast to within category discrimination, crossing the phoneme boundary appears to result in larger MMN [16], and the amplitude is reduced near the perceptual magnet (when individually selected stimuli are used)[1]. If the two phoneme systems of Finnish and Swedish are separately stored and accessed in balanced bilinguals, this should result in stronger MMN responses in between category vowel pairs in comparison with within category stimuli.

3.1. Procedure

The subjects participated in the EEG recording after the ID-experiment in a similar manner as in Experiment 1. They watched a silent movie of their choice during the registration and were monitored via a video system. We recorded EEG (sampling rate 250 Hz, bandwidth 0.5-70 Hz) form the scalp with Sn electrodes (a 21 channel electrocap, Electro-Cap International, Inc.) using the Synamps (model 5083) amplifier. Eye movements were monitored by two electrodes attached below and near the outer canthus of the right eye.

3.1.1. Subjects and stimuli

The same 12 subjects as in Experiment 1 participated in the EEG recordings. The stimuli were also the same and they were presented in the oddball paradigm in two blocks. There were 783 standards and 120 deviants (p = 0.133) in one block.

3.1.2. Analysis

The obtained continuous EEG was digitally filtered off-line using a bandpass filter (1-30 Hz). The artefact criterion was set at ± 100 µV. Separately averaged waveforms (a 600 ms window including a 100 ms pre-stimulus baseline period) for the standard and the deviant stimuli were computed for each subject and difference waveforms were created by subtracting the response to the standard stimulus from that to the deviant stimulus. We chose two consecutive 50 ms time windows (180-230 ms, 230-280 ms) around the maximum peak amplitudes and measured the mean amplitudes from these windows. We then subjected the obtained mean amplitudes from Fz electrode to a 2 (context language) x 2 (phonological system) x 2 (time window) Repeated measures ANOVA.

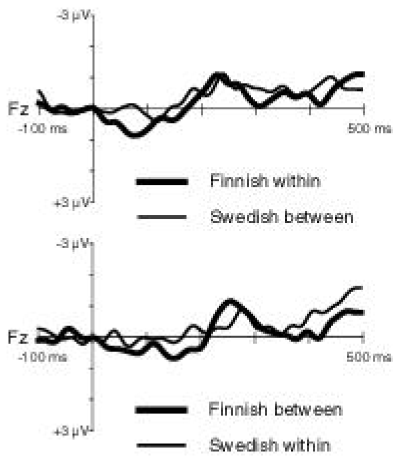
3.2. Results

There are no visible language context related differences in the waveforms nor in the mean amplitudes (see Table 2 and Fig. 1). This was also supported by the statistical analysis, which showed no effect of the linguistic context (f(1,11)=0.010, p=0.922, n.s.). In addition, the effect of the phonological status of the stimulus pair was non-significant (f(1,11)=0.015, p=0.906, n.s.) revealing that the crossing of the category boundary did not result in a larger MMN. The linguistic context and the phonological status of the stimuli did not depend on each other, since the interaction was not significant (f(1,11)=0.947, p=0.351, n.s.). The only statistically significant finding was that the MMN amplitude was different in the two time windows (f(1,11)=13.287, p=0,004), which merely shows that the peaks were more accurately captured – irrespective of the context and the stimulus pair – by the second time window. Altogether, this suggests that the vowel contrasts are automatically perceived in a similar manner in both contexts, so that the phonological status is not dependent upon the ambient language.

Table 2: The mean MMN amplitudes in microvolts (µV) evoked in the Finnish and Swedish language contexts by the between (btw) and within category stimulus pairs in two time windows (180-250, 230-280 ms).

	Finnish	Swedish
btw 1	-0.140	-0.551
btw 2	-1.012	-0.857
within 1	-0.561	-0.239
within 2	-0.839	-0.487

Figure 1: The grand average waveforms from Fz electrode to both vowel pairs in both linguistic contexts.



4. DISCUSSION

Bilingualism is based on neural plasticity, which facilitates the automatic perception of speech sounds in both languages. However, there are partly contradicting results showing that the two languages have overlapping neural activation areas [5] and that language learning may [18], or may not [12] result in the formation of new automatically responding memory traces. In addition, it seems that bilinguals either keep [17], or do not keep [11] the two systems apart. Our present results suggest that bilinguals have an intertwined phonological system, which, more importantly, does not have two systems separately activated by the linguistic context. The intertwined system, which includes neural representations for the speech sounds of both languages, is constantly "switched on".

Our results are partly in accordance with the results by Hernandez et al. [5] and Winkler et al. [17]. However, in Hernandez et al. the task demanded translation from one language to another, while our study merely monitored the automatic processing, or (in the case of Experiment 1) processing which does not demand metalinguistic knowledge. This suggests that the preattentive processing is not dependent upon the context. In contrast to Winkler et al., the subjects in the present study were balanced bilinguals. Taken together, it seems that, if a new language is learned in an authentic context, even at adult age, then the two systems become intertwined in a similar manner as in balanced bilinguals, suggesting a similar neural basis. When the present results are contrasted with those by Peltola and Aaltonen [11] showing that the two separate systems in fluent second language learners are activated by the context, it seems evident that balanced bilingualism cannot be based on the same perceptual mechanisms as the bilingualism obtained in classroom.

Our results suggest that balanced bilinguals do not keep their two phonological systems apart. This implies that the two systems are neurally intertwined and that they are equally efficiently activated in response to either of the languages.

4. ACKNOWLEDGEMENTS

We wish to thank Prof. Jyrki Tuomainen for his help and the Academy of Finland for financial support (project number 8206352).

5. REFERENCES

[1] Aaltonen, O., Eerola, O., Hellström, Å., Uusipaikka, E., Lang, A.H., 1997. Perceptual magnet effect in the light of behavioral and psychophysiological data. *J. Acoust. Soc. Am.* 101, 1090-1105.

[2] Albert, M.L., Obler, L.K. 1978. *The Bilingual Brain. Neurophysiological and Neurolinguistic Aspects of Bilingualism.* New York: Academic Press.

[3] Bloomfield, L. 1933. *Language*. New York: Academic Press.

[4] Grosjean, F. 1989. Neurolinguist beware! The bilingual is not two monolinguals in one person. *Brain and Language* 36, 3-15.

[5] Hernandez, A.E., Dapretto, M., Mazziotta, J., Bookheimer, S. 2001. Language Switching and Language Representation in Spanish-English Bilinguals: An fMRI Study. *NeuroImage* 14, 510-520.

[6] Iverson, P., Kuhl, P.K. 2000. Perceptual magnet effect and phoneme boundary effect in speech perception: Do they arise from a common mechanism? *Perception & Psychophysics* 62, 874-886.

[7] Lehtola, H., Tamminen, H., Peltola M.S., Aaltonen, O. 2007. Vowel identification in balanced bilinguals. This volume.

[8] Liberman, A.M. 1957. Some results of research on speech perception. *J. Acoust. Soc. Am.* 29, 117-123.

[9] Näätänen, R., Gaillard, A.W.K., Mäntysalo, S. 1978. Early selective attention effects on voluntary and involuntary attention. *Acta Psychologica* 42, 313-329.

[10] Näätänen, R., Lehtokoski, A., Lennes, M., Cheour, M., Huotilainen, M., Iivonen, A., Vainio, M., Alku, P., Ilmoniemi, R.J., Luuk, A., Allik, J., Sinkkonen, J. Alho, K. 1997. Language-specific phoneme representations revealed by electric and magnetic brain responses. *Nature* 385, 432-434.

[11] Peltola, M.S., Aaltonen, O. 2005. Long-term memory trace activation for vowels depends on the mother tongue and the linguistic context. *Journal of Psychophysiology* 19, 159-164.

[12] Peltola, M.S., Kujala, T., Tuomainen, J., Ek, M., Aaltonen, O., Näätänen, R. 2003. Native and foreign vowel discrimination as indexed by the mismatch negativity (MMN) response. *Neuroscience Letters* 352, 25-28.

[13] Peltola, M.S., Kuntola, M., Tamminen, H., Hämäläinen, H., Aaltonen, O. 2005. Early exposure to a non-native language alters prattentive vowel discrimination. *Neuroscience Letters* 388, 121-125.

[14] Perani, D., Dehaene, S., Grassi, F., Cohen, L., Cappa, S.F., Dupoux, E., Fazio, F., Mehler, J. 1996. Brain processing of native and foreign languages. *Neuroreport* 7, 2439-2444.

[15] Perani, D., Paulesu, E., Sebastian-Galles, N., Dupoux, E., Dehaene, S., Bettinardi, V., Cappa, S.F., Fazio, F., Mehler, J. 1998. The bilingual brain: proficiency and age of acquisition of the second language. *Brain* 121, 1841-1852.

[16] Sharma, A., Dorman, M.F. 1999. Cortical auditory evoked potential correlates of categorical perception of voice-onset time. *J. Acoust. Soc. Am.* 106, 1078-1083.

[17] Winkler, I., Kujala, T., Alku, P., Näätänen, R. 2003. Language context and phonetic change detection. *Cognitive Brain Research* 17, 833-844.

[18] Winkler, I., Kujala, T., Tiitinen, H., Sivonen, p., Alku, P., Lehtokoski, A., Cziegler, I., Csepe, V., Näätänen, R. 1999. Brain responses reveal the learning of foreign language phonemes. *Psychophysiology* 36, 638-642.

[19] Winkler, I., Lehtokoski, A., Alku, P., Vainio, M., Cziegler, I., Alho, K., Lang, H., Iivonen, A., Näätänen, R. 1999. Pre-attentive detection of vowel contrasts utilizes both phonetic and auditory memory representations. *Cognitive Brain Research* 7, 357-369.