Plasticity of illusory vowel perception in Brazilian-Japanese bilinguals

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Previous research shows that monolingual Japanese and Brazilian Portuguese listeners perceive illusory vowels (/u/ and /i/, respectively) within illegal sequences of consonants. Here, several populations of Japanese-Brazilian bilinguals are tested, using an explicit vowel identification task (experiment 1), and an implicit categorization and sequence recall task (experiment 2). Overall, second-generation immigrants, who first acquired Japanese at home and Brazilian during childhood (after age 4) showed a typical Brazilian pattern of result (and so did simultaneous bilinguals, who were exposed to both languages from birth on). In contrast, late bilinguals, who acquired their second language in adulthood, exhibited a pattern corresponding to their native language. In addition, an influence of the second language was observed in the explicit task of Exp. 1, but not in the implicit task used in Exp. 2, suggesting that second language experience affects mostly explicit or metalinguistic skills. These results are compared to other studies of phonological representations in adopted children or immigrants, and discussed in relation to the role of age of acquisition and sociolinguistic factors. © *2010 Acoustical Society of America.* [DOI: 10.1121/1.3327792]

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I. INTRODUCTION

The question of functional plasticity for second language acquisition is still hotly debated. The claim that there is a decline with age in the ability to achieve native-like performance in a second language is not controversial (Flege *et al.*, 1999b; Hakuta *et al.*, 2003). What is controversial, however, is whether this decline is due to a biologically based critical period (Lenneberg, 1967), increased interference between the native language and the second language (Iverson *et al.*, 2003; Pallier *et al.*, 2003), social/motivational variables (Bialystok and Hakuta, 1994; Flege *et al.*, 1999a), or lifelong general decline in cognitive abilities (see Hakuta *et al.*, 2003).

One of the battlegrounds for this debate is the effect of the native language phonology onto the perception of second language sounds. In this area, several studies point to a very early onset of language acquisition (between 6 and 12 months of age, Werker and Tees, 1984a; Kuhl *et al.*, 1992) as well as a severe age-related decline in the ability to process the sounds of a second language (Flege, 1995). For instance, Japanese late learners of English have a persistent deficit in processing some non-native contrasts, such as /r/ versus /l/ (Goto, 1971; Miyawaki *et al.*, 1981). Even if some residual learning capacity is present in adults, as shown by training studies, the final performance is nowhere as good as the monolinguals' one (Logan *et al.*, 1991; 1993), and seems to rely on different cues from those used by monolinguals (Yamada, 1993; Iverson *et al.*, 2003; 2005).

Pallier *et al.* (1997) found that Spanish-Catalan bilinguals who were only exposed to Spanish at home before age 4, and were extensively exposed to Catalan thereafter, have extreme difficulties in processing Catalan vocalic contrasts that do not exist in Spanish (/*e*/-/ɛ/ and /o/-/ɔ/). This effect has been replicated using a variety of tasks (Pallier *et al.*, 2001; Sebastián-Gallés and Soto-Faraco, 1999), and is compatible with a very early critical period for the perception of language-specific sounds (i.e., a loss in plasticity taking place before age 4). In contrast, Ventureyra *et al.* (2004) found that Korean children adopted into a French family between 4 and 7 years of age did not only acquire a perfect phonology for their adopted language, but appeared to have lost their native language phonology. This rather spectacular result shows that a complete remapping of the native phonetic categories onto foreign ones remains possible at least until age 7. If so, the early period of plasticity should be extended until this age, contrary to a possible interpretation

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of the Catalan-Spanish bilingual data discussed above. The complete loss of early acquired phonetic categories, however, is itself questioned by studies showing lasting effects of early exposure to the non-dominant language. Tees and Werker (1984) and Au *et al.* (2002) reported that subjects who heard or practiced a language during childhood, but ceased to do so afterwards, are faster to relearn this language once tested in adulthood. Oh *et al.* (2003) replicated this result using a population of Korean immigrants or children of immigrants in the US, who were exposed to Korean during childhood, but switched to English before adolescence, and ceased to use Korean. Oh *et al.* (2003) found that once adults, these subjects were better able to relearn Korean than English native speakers who had not been exposed to Korean during their childhood. This suggests that contrary to the data of Ventureyra *et al.* (2004), early exposure to a language (i.e., before age 4) has a lasting effect on perception.

The discrepancy between these results could be due to two factors. The first factor is methodological. These studies used different kinds of tests, several of them off-line and rather explicit. Indeed, in an off-line situation, participants have the possibility of developing metalinguistic or metacognitive compensation strategies, which are not available in more difficult or speeded situations. For example, Sebastián-Gallés and Soto-Faraco (1999) found that even those Spanish-Catalan bilinguals, who reached a performance similar to native Catalan speakers when tested with an off-line task (categorizing nonwords in an unspeeded way), needed a longer portion of the stimulus to recognize it when tested in a forced-choice gating paradigm (see also the results of Pallier *et al.*, 2001, who used a speeded lexical decision task). In order to compare different studies, it is therefore important to control such task-related variables. The second factor is the sociolinguistic difference between foreign adoption and immigration. In the former case, adopted children are totally cut off from their native culture, environment, and language, and are transplanted into a completely new environment. In the latter case, immigrant children or children from first-generation immigrants remain in contact with their original culture and language even if they get well-integrated into their new environment.

In the present study, we focus on a situation of immigration, comparable to the study of Oh *et al.* (2003) with Japanese immigrants in Brazil. The main variables of interest will be age of exposure to the second language, and amount of continued exposition to the first language. First-generation immigrants were exposed to Japanese until they immigrated as adults in Brazil, where they learned Brazilian Portuguese and continued to use Japanese at home. Second-generation immigrants were exposed to Japanese at home, but switched to Brazilian Portuguese when they entered school (around age 6). Children in the simultaneous bilinguals group are from mixed families, with one Brazilian Portuguese parent and the other from Japanese origin. They have been exposed to both languages at birth, but switched to Brazilian Portuguese at school. Finally students of Japanese were native speakers of Brazilian Portuguese, who started to acquire Japanese formally when they were teenagers or adults.

In our study, we exploit a phonologically influenced perceptual illusion that arises in the perception of illegal consonant sequences. In both Japanese and Brazilian Portuguese, stop consonants are illegal in the coda position of syllables. As a consequence, strings such as "ebna" are phonologically illegal in both languages and give rise to the robust perception of an illusory "epenthetic" vowel, which breaks up the illegal consonant string. In Japanese, the epenthetic vowel is "u" (ebna→ebuna; Dupoux *et al.*, 1999; Dupoux *et al.*, 2001a), while in Brazilian Portuguese, the epenthetic vowel is "i" (ebna→ebina; Dupoux *et al.*, submitted). Therefore, in this study, we probe for the perception of this illusory vowel, by presenting the same illegal sequences of consonants to various groups of participants, in order to determine whether they have a Japanese-like or a Brazilian-like phonology. In order to take into account the nature of the task, we ran two studies: Experiment 1 uses an off-line explicit task, vowel identification (as in Dupoux *et al.*, 1999), whereas Experiment 2 uses an implicit on-line task, speeded sequence recall (as in Dupoux *et al.*, 2001b).

II. EXPERIMENT 1

In this experiment, we tested the perception of illegal consonant clusters in a vowel identification task. The participants were presented with naturally produced bisyllabic stimuli with a medial consonant cluster, which was illegal both in Brazilian Portuguese and in Japanese, such as "ebna." Monolingual speakers of both languages typically insert a vowel to break this illegal consonant cluster: The vowel /i/ in Brazilian Portuguese, and the vowel /u/ in Japanese. The participants were required to decide whether the stimuli contained or not a vowel between the two consonants, and if yes, which vowel it was, among five possible responses: a, e, i, o, and u. This design was very similar to that used in the first and second experiments of Dupoux *et al.* (1999).

A. Method

1. Sociolinguistics background of the bilingual participants

There is a strong Japanese community in Brazil, which allowed us to find a large enough number of bilingual subjects. Japanese immigration to Brazil started in the beginning of the 20th century with the arrival of people who worked in coffee farms. The pressure for emigration in Japan was caused by the social tension due to its high population growth. In 1930 Brazil had the largest Japanese colony in the world, outside of Japan. Nowadays, there are about 1,500,000 Japanese people and their descendants in Brazil, of whom 370,000 live in the city of São Paulo.

The Japanese community in Brazil has been subjected early on to discrimination as well as a strong pressure toward linguistic assimilation. During the Second World War, the Brazilian government banned the Japanese immigrants to hold meetings, to travel, and to participate in associations. Japanese publications were banned from circulation; and the use and teaching of the Japanese language in Brazil was prohibited. Within the Japanese district in São Paulo (the

TABLE I. Biographical data and subjective ratings for the four Japanese-Brazilian Portuguese bilingual populations. The values given are means, with ranges in square parenthesis [min, max]. Note that the questionnaire data were lost for the group of first-generation immigrants (the computer and questionnaire sheets were stolen), so that only the means are available for the biographical data, while subjective ratings were completely lost (the gist of the subjective ratings was that their Japanese was very good and their Brazilian Portuguese was rather poor).

		First-generation Japanese immigrants (N=8)	Second-generation Japanese immigrants (N=32)	Simultaneous bilinguals (N=40)	Students of Japanese (N=15)
		Biographical data			
Sex	% male	25.0	65.6	65	33.2
	% female	75.0	34.4	35	66.2
Age at test		64	53 [18, 71]	30 [13, 70]	29 [16, 52]
Age of first exposition to Brazilian Portuguese		30	6 [4, 8]	0 [0, 0]	0 [0, 0]
Age of first exposition to Japanese		0	0 [0, 0]	0 [0, 0]	18 [6, 49]
Number of years spent in Brazil		36.0	52 [17, 71]	30 [13, 70]	27 [16, 50]
Number of years spent in Japan		28.0	1.5 [0, 14.3]	0.4 [0, 8.5]	1.6 [0.1, 11.7]
Use of Japanese (%)	Between 0 and 5 years	100	99 [80, 100]	39 [10, 90]	0 [0,0]
	Current usage	55	13 [0, 50]	5 [0,60]	14 [0, 80]
		Subjective ratings [on a scale from 0 (very poor) to 10 (excellent)]			
Brazilian Portuguese	Comprehension	-	9.3 [5,10]	9.5 [6, 10]	9.7 [8, 10]
	Production	-	9.2 [5, 10]	9.4 [7, 10]	9.5 [8, 10]
	Accent	-	8.7 [5, 10]	8.9 [1, 10]	9.7 [7, 10]
Japanese	Comprehension	-	6.4 [2, 10]	4.0 [1, 9]	3.9 [1, 7]
	Production	-	5.8 [0, 10]	3.1 [1, 8]	3.9 [1, 7]
	Accent	-	6.0 [1, 10]	3.9 [1, 10]	4.7 [1, 9]

Liberdade), schools have Brazilian Portuguese as the main language, the second language being English, and Japanese only as an option. Nowadays, even in the Centro Educacional Pioneiro, a private school founded in 1971, which contains 90% of students of Japanese descent, all the courses on Japanese tradition, including language, are optional, and are followed mostly by students of non-Japanese descent who plan to work in Japan. These numbers suggest that the pressure toward linguistic and social integration has been pervasive.

2. Participants

Ninety-five Brazilian-Japanese bilinguals participated in this experiment. Ninety-three bilinguals lived and were tested in São Paulo and two lived in Tokyo but were tested during a short visit in São Paulo.

Among these 95 bilingual subjects, eight were immigrants from the first generation, born in Japan. Thirty-two were immigrants from second-generation: Both their parents had been born in Japan, but they themselves were born in Brazil; they first learned to speak Japanese with their parents, then started to learn Brazilian Portuguese at school, after the age of 4–8 years. Forty were simultaneous bilinguals, with one Brazilian parent, and the other from a Japanese family (who learned Japanese in early childhood). Finally, 15 were native Brazilians, who started to study Japanese when they were teenagers or adults, either for professional reasons, or because it was an option in high school. In addition to the Japanese courses, some of these bilinguals were exposed to some Japanese during late childhood/adolescence.

There were two control groups, a group of 27 native speakers of Japanese, who lived and were tested in Tokyo, and a group of 15 native speakers of Brazilian Portuguese, who lived and were tested in São Paulo. None of these participants were bilingual, and none had a known hearing deficit.

The 95 bilinguals included in the study were interviewed regarding their language background (see Table I). They provided detailed information concerning their first 5 years of life (who took care of them and in what language they were spoken to by various people in their environment) as well as their current situation [language(s) spoken at home, at school/work, with friends and siblings; frequency and length of visits to Japan]. The bilinguals also rated on a scale from 1 to 10 the importance of Japanese and Brazilian Portuguese in their own lives, as well as their current Portuguese and Japanese competence in three domains, i.e., comprehension, pronunciation, and accent (see Table I).

Table I gives the mean age of first exposition to both languages. First-generation immigrants learned Japanese first, then Brazilian Portuguese once they were adults (mean age of acquisition of 30 years). Second-generation bilinguals learned Japanese at home, from birth on, then Brazilian Portuguese when they entered school (mean age of acquisition of 6 years). Simultaneous bilinguals learned both languages from birth on. Finally, the students of Japanese learned Brazilian Portuguese as a first language, and started to study Japanese when they were teenagers or adults (although some of them had been exposed to Japanese in late childhood, after age 6).[1] Another variable which clearly distinguishes the groups of bilingual is the percentage of use of each language: Only the immigrants from first generation use mainly Japanese, while the four other groups of bilinguals use mainly Brazilian Portuguese and have small percentages of use of Japanese (between 5% and 15%). Lastly, the self-evaluation scores with regard to oral comprehension, production, and

TABLE II. Mean percentage of responses u, i, other vowels (a, e, or o), and no vowel, for two populations of monolingual speakers and four populations of bilingual speakers (standard errors of the means are in parenthesis). The response percentages for /i/ and /u/ are also shown in Fig. 1.

	u	i	Other vowel (a, e, o)	No vowel
Japanese monolinguals	58.7(4.7)	9.4(1.8)	4.3(1.5)	27.6(5.1)
First-generation Japanese immigrants	68.3(4.2)	25.0(3.8)	0.9(0.9)	5.8(3.2)
Second-generation Japanese immigrants	23.1(3.4)	49.5(5.4)	2.4(1.7)	25.0(5.7)
Simultaneous bilinguals	23.9(3.1)	43.7(4.9)	4.0(1.5)	28.5(4.8)
Students of Japanese	33.9(5.9)	26.7(7.0)	3.1(1.3)	35.9(8.5)
Brazilian Portuguese monolinguals	5.6(1.8)	65.6(6.1)	8.7(3.5)	20.0(5.9)

accent show that most of the bilingual groups judge their Brazilian Portuguese to be better than their Japanese, with the exception of first-generation immigrants who considered their Japanese to be better than their Brazilian Portuguese (the self-evaluation data for this group are absent from Table I because they were lost; however, this clearly came out from the informal interviews).

3. Stimuli

Thirteen $V_1C_1C_2V_2$ experimental stimuli were selected, where V_1 and V_2 are vowels in the set /a,e,i,o/, C_1 is a stop consonant, and C_2 is a stop or a nasal consonant (the full list of stimuli was abda, abdo, adgi, agno, akpa, apti, ebdo, ebna, epta, epto, ibna, igba, and igna). In addition, the experiment contained a large number of filler items ($N=182$) consisting in $V_1C_1VC_2V_2$ stimuli where the middle V was one of the following vowels: /a/, /o/, /i/, and /u/. The /i/ and /u/ fillers were arranged along a six-step vowel duration continuum, varying from full vowel to no vowel. Overall, participants were therefore presented with a large range of stimuli, and had the opportunity to use all of the available response categories to describe their perception of the segment between C_1 and C_2. The data of the filler items were not analyzed in the present study. They belong to a separate experiment on perception of coarticulation that focuses on monolingual speakers of Japanese, Brazilian Portuguese, and European Portuguese, and are described in Dupoux *et al.* (submitted).

All stimuli were nonwords in Japanese and Brazilian, as well as in French. The stimuli were recorded by a native speaker of French, who was able to produce them naturally, since all stimuli were phonotactically legal in French. The acoustic characteristics of the experimental stimuli are listed in the Appendix.

4. Procedure

Participants were presented with one auditory stimulus at a time, and had to judge whether it contained a middle vowel, and if yes, what this vowel was. They had to fill in a response sheet, where each stimulus was presented orthographically in the form $V_1C_1?C_2V_2$ (e.g., eb?na), and a six forced-choice alternative was given for each stimulus ("a," "e," "i," "o," "u," and "no vowel"). The stimuli were concatenated into a single audio file, in a pseudo-random order (the same order for all participants) and were presented to the participants over headphones. Participants were told that all stimuli had the same form /VC(V)CV/, and they had to concentrate on the presence and identity of the medial vowel. The experiment lasted 20 min.

B. Results

The percentage of responses to the experimental stimuli are shown in Table II (i, u, other vowel (a,e, or o), or no vowel). The results show that on average, participants have a no-vowel response rate comprised between 20% and 36%, which corresponds to what is typically found with these populations (Dupoux *et al.*, 1999) (with the exception of first-generation immigrants, who have only 5% no-vowel responses). The rest of the responses are the epenthetic vowels, with the majority of responses falling within the /i/ and /u/ categories (represented in Fig. 1), and the control vowels /a/, /e/, and /o/ receiving at most 9% of responses altogether. To assess which epenthetic vowel was preferentially chosen for each population, we computed $D_{\text{i versus u}}$, which is the average /i/ minus /u/ difference score for each participant, and submitted this score to two analyses of variance (ANOVAs), one with participants as the random variable, with the between-subjects factor population (six modalities, four groups of bilinguals, and two control groups of monolinguals), and one with items as the random variable with the within-item factor population.

We found a significant effect of population [$F1(5,131)=26.4$, $p<0.00001$; $F2(5,60)=32.2$, $p<0.00001$; $\text{MinF}'(5,176)=14.5$, $p<0.0001$]. As expected, the Japanese monolinguals showed a negative difference score ($D_{\text{i versus u}}=-49.3$, se=5.0, $p<0.0001$), with a majority of /u/ responses, and the Brazilian monolinguals showed a positive difference score ($D_{\text{i versus u}}=60.3$, se=6.6, $p<0.0001$),

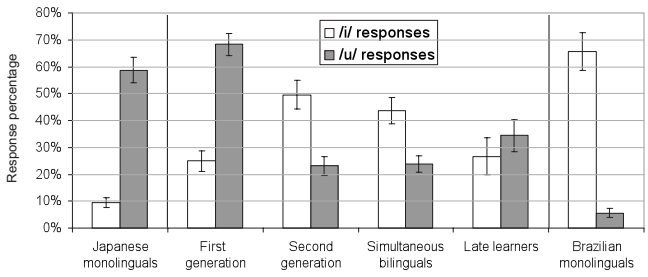

FIG. 1. Percentage of illusory u and i responses in stimuli containing an illegal consonant cluster, in six populations of participants with varying degrees of exposure to Japanese and Brazilian Portuguese.

with a majority of /i/ responses (see Fig. 1, left- and rightmost bars). This effect was highly significant [$F1(1,40)=173.4$, $p<0.001$; $F2(1,12)=151.6$, $p<0.001$; $MinF'(134)=80.8$, $p<0.0001$]. The first-generation immigrants had a significant negative difference score ($D_{\text{i versus u}}=-43.3$, se=7.4, $p<0.001$), thus behaving like the Japanese monolinguals; second-generation immigrants and simultaneous bilinguals had a positive difference score (respectively, $D_{\text{i versus u}}=26.4$, se=6.9, $p<0.001$; $D_{\text{i vs u}}=19.8$, se=6.7, $p<0.005$), thus behaving like the Brazilian monolinguals; finally, the students of Japanese were "in-between," with a balanced use of /i/ and /u/ as epenthetic vowel ($D_{\text{i versus u}}=-7.7$, se=9.8, $p>0.1$; see Fig. 1). Interestingly, we found in this group a significant positive correlation between the age of first exposure to Japanese and the /i/ versus /u/ difference score [$R=0.88$; $F(1,13)=43.9$, $p<0.0001$]. This was due to the fact that the students of Japanese who had been exposed the earliest to Japanese showed a Japanese-like negative difference score ($D_{\text{i versus u}}=-28.0$ for the nine participants exposed to Japanese at or before age 15), while the later exposed participants showed a Brazilian-like positive difference score ($D_{\text{i versus u}}=23.0$ for the six participants who were exposed to Japanese after age 15).

Multiple comparisons between each of the monolingual control groups and each of the four groups of bilinguals with Bonferroni correction, showed that the Japanese monolinguals differed from all the bilingual populations (corrected $p<0.006$), except the first-generation immigrants (corrected $p>0.1$), and that the Brazilian monolinguals differed from the first-generation immigrants (corrected $p<0.001$), from the simultaneous bilinguals (corrected $p<0.03$), and from the students of Japanese (corrected $p<0.001$), but not from the second-generation immigrants (corrected $p<0.1$).

C. Discussion

Monolingual Japanese participants mainly perceived the stimuli as containing the epenthetic vowel /u/, while monolingual Brazilian participants mainly perceived the epenthetic vowel /i/, as expected. Of particular interest to us was the behavior of bilingual participants: First-generation immigrants appeared to behave like Japanese monolinguals, suggesting that their immersion within a Brazilian-speaking country, which started in adulthood, did not induce them to significantly modify their phonological settings. In sharp contrast, second-generation immigrants behaved like Brazilian monolinguals, with a positive difference score: Recall that these bilinguals were exposed mostly to Japanese (within their family and community) during the first 4–8 years of their lives, then switched to Brazilian when they entered the schooling system. This result thus suggests that the early exposure to Japanese did not influence significantly the end result of the phonological acquisition. Similarly, simultaneous bilinguals behaved mostly like Brazilian monolinguals. Finally, students of Japanese show an in-between behavior, intermediate between what Japanese and Brazilian monolinguals do. This may reveal an impact of the languages that are currently used by the participants, since at least some of the students of Japanese use it for professional reasons, or of the effect of formal training in Japanese. Yet, the Japanese pattern of result was due to those participants who had been already exposed to Japanese during late childhood/adolescence, which is consistent with previous findings that formal training or professional usage can reactivate formerly acquired phonological patterns (Tees and Werker, 1984; Au *et al.*, 2002).

Before we move on, let us notice a general tendency on the percentage of non-preferred vowel responses (/i/ for Japanese listeners and /u/ for Brazilian listeners). As is apparent in Fig. 1, both monolingual groups show very small percentages of non-preferred vowel responses (below 10%). In contrast, all groups of bilinguals show an increased percentage of non-preferred vowel responses (over 20% for all four groups). This is true even for the first-generation bilinguals who appear otherwise to behave exactly like Japanese monolinguals. This suggests to us that bilingual speakers are aware that their languages make different choices for epenthetic vowels, and that both /i/ and /u/ are valid choices, even when they retain a strong preference for one of the options.

Before drawing firm conclusions from these data, we wish to replicate them with an implicit/on-line task. Indeed, as discussed in Sec. I, performance may vary depending on whether the task was off-line/explicit and could be influenced by metalinguistic or metacognitive strategies or on-line/implicit, and tapped more directly phonological processing abilities (Sebastián-Gallés and Soto-Faraco, 1999). In the next experiment, we exploit a variant of the sequence recall task developed by Dupoux *et al.*, (2001b) that has been claimed to be a good measure of the on-line phonological encoding of speech sounds (Dupoux *et al.*, 2008).

III. EXPERIMENT 2

In Dupoux *et al.*, (2001b), participants first learned an association between two nonwords and two computer keys (e.g., ebna=1 and ebuna=2). Next, they were presented with random sequences of various lengths (2–6) composed of these two nonwords, and were asked to reproduce the corresponding keyboard sequences. Because the sequences were played in very fast succession (compressed stimuli, 50 ms of interstimulus interval, ISI), and because a given nonword was instantiated by several acoustically distinct tokens, participants could not perform the task by relying on high-level explicit recoding strategies (e.g., orthographic recoding) nor on low-level acoustic mismatch signals. Dupoux *et al.* (2001b) claimed that such a task taps specifically the content of the phonological short-term memory buffer, and hence, can be used to study the format of phonological representations.

Note that this paradigm differs from that used in experiment 1 in two respects. First, experiment 1 used an explicit judgment about the presence and identity of a "vowel" that is embedded inside a word. The notion of vowel, together with the ability to explicitly segment phonemes out of continuous speech, rests on metalinguistic skills, whose mastery depend on the learning of an alphabetic writing system (Morais *et al.*, 1979; Liberman *et al.*, 1974). Critically, illiterate participants are very poor at phoneme detection or classification

tasks. In contrast, in the procedure of Dupoux *et al.* (2001b), the stimuli are presented as unsegmented wholes, and the discrimination of the phonological contrast under study is only implicit. Second, experiment 1 used an unspeeded procedure, whereby subjects could use a variety of alternative strategies to generate their responses. In contrast, the procedure of Dupoux *et al.* (2001b) appears much more on-line, due to the rapid decay of the auditory memory buffer, and the speed of presentation of the linguistic materials.

In the present experiment, we introduced a modification to the original paradigm in order to test whether the implicit nature of the task and the on-line constraint are both necessary to limit the accessibility of metalinguistic strategies. Specifically, after participants were trained with a pair of nonwords, they were presented with only one stimulus at a time and had to classify it using the computer keys. This task, which we call a forced-choice categorization task, has the implicit nature of the task of Dupoux *et al.* (2001b), but is not on-line. This was then followed by a classical sequence recall task (using only sequences of four nonwords). Both tasks provide feedback in case of errors, in order to minimize the possibility that participants might simply forget which nonword goes with which key.

In the present experiment, we tested three conditions. In a control condition, the pair of nonwords was of the type "ebuna" and "ebina," which are two stimuli that differ by their medial vowel, and receive distinct phonological representations in all speakers, whatever their native language. This allowed us to measure baseline performance. In the second and third conditions, participants were tested on pairs such as "ebna/ebina" and "ebna/ebuna," respectively. The stimulus ebna contains an illegal cluster in both Brazilian and Japanese, but by hypothesis, this cluster is phonologically repaired differently in the two languages. According to experiment 1, Brazilian monolingual listeners phonologically encode it as ebina, whereas Japanese monolinguals encode it as ebuna. As a result, we expect Brazilian listeners to make lots of errors in the ebna/ebina pairs, whereas Japanese listeners should have problems with the ebna/ebuna pair. Testing our bilingual populations with this task should therefore enable us to probe for their phonological encoding of illegal clusters.

A. Method

1. Participants

Eighty-one Brazilian-Japanese bilinguals participated. They were the same participants as in experiment 1, except for the first-generation bilinguals, who were unwilling to perform the sequence recall task: They had no experience with a computer keyboard, and failed to associate the response keys with the stimuli in the first condition (control). For the same reasons, four participants from the second-generation group and two simultaneous bilinguals failed to complete the experiment. This experiment thus featured 28 second-generation bilinguals, 38 simultaneous bilinguals, and 15 students of Japanese. All participants performed experiment 1 first, and experiment 2 (on the same day). In addition, 33 Japanese monolinguals were tested in Tokyo, and 24 Brazilian monolinguals were tested in São Paulo. These were not necessarily the same monolinguals as in experiment 1.

2. Stimuli

Using only one stimulus type for all three conditions, namely, ebina/ebuna, ebna/ebina, and ebna/ebuna, would have been problematic because participants would have had to reassign the same stimulus to two different keys (left in one case, right in the other), and this may have led to confusions. Therefore, we selected three of the stimuli from experiment 1 for this experiment: "agno" was used for the control condition (agino versus aguno), "ibna" was used for the ibna versus ibuna condition, and "abda" was used for the abda versus abida condition. All six stimuli, i.e., agino, aguno, abda, abida, ibna, and ibuna, were pronounced once each by three men and three women, all native speakers of French (a language in which these structures are all legal). Thus, there were 36 stimuli overall (see the Appendix for their prosodic characteristics). The stimuli were temporally compressed to 70% of their original duration, using PRAAT (http://www.praat.org/). For ease of exposition, we will continue to use ebna as the model stimulus, and will refer to the three conditions from this experiment as ebna/ebuna, ebna/ebina, and ebina/ebuna.

3. Procedure

The experiment consisted of three conditions, all three performed successively in the same experimental session. In each condition, participants had to distinguish between pairs of stimuli. Condition 1 contained the stimulus pair agino-aguno, which should be easy for everybody and act as a baseline. In conditions 2 and 3, participants processed both contrasts that involved the item with a cluster: abda-abida and ibna-ibuna. The order of presentation of these last two conditions was counterbalanced across participants.

For each condition, participants first went through a phase during which they learned to associate the stimuli with the keys of the computer, i.e., "1" and "2" (in what follows, we illustrate the procedure by using aguno and agino as the stimulus types). In the beginning, participants had the opportunity to trigger the presentation of aguno and agino stimuli by pressing on the keys 1 and 2. Once they had heard these stimuli as often as they wanted, the categorization phase started. In this phase, the computer played only one stimulus at a time, followed by the word "okay," and the subjects were to decide if it belonged to category 1 or 2 by pressing the corresponding key. The computer gave them feedback on their answer. This phase contained 24 trials (12 for each stimulus type). Then participants went on to perform the sequence recall phase. They first got four trials of training with sequences of two stimuli; for instance, if they heard aguno-agino, they had to press 1-2, if they heard aguno-aguno, they had to press 1-1. They received feedback on these four trials. Then they were switched to the sequence recall test phase, during which they received 24 trials. Each trial consisted of a sequence of four stimuli presented in fast succession (120 ms of ISI), followed by the word Okay (this was done in order to prevent them from typing their response as they were listen-

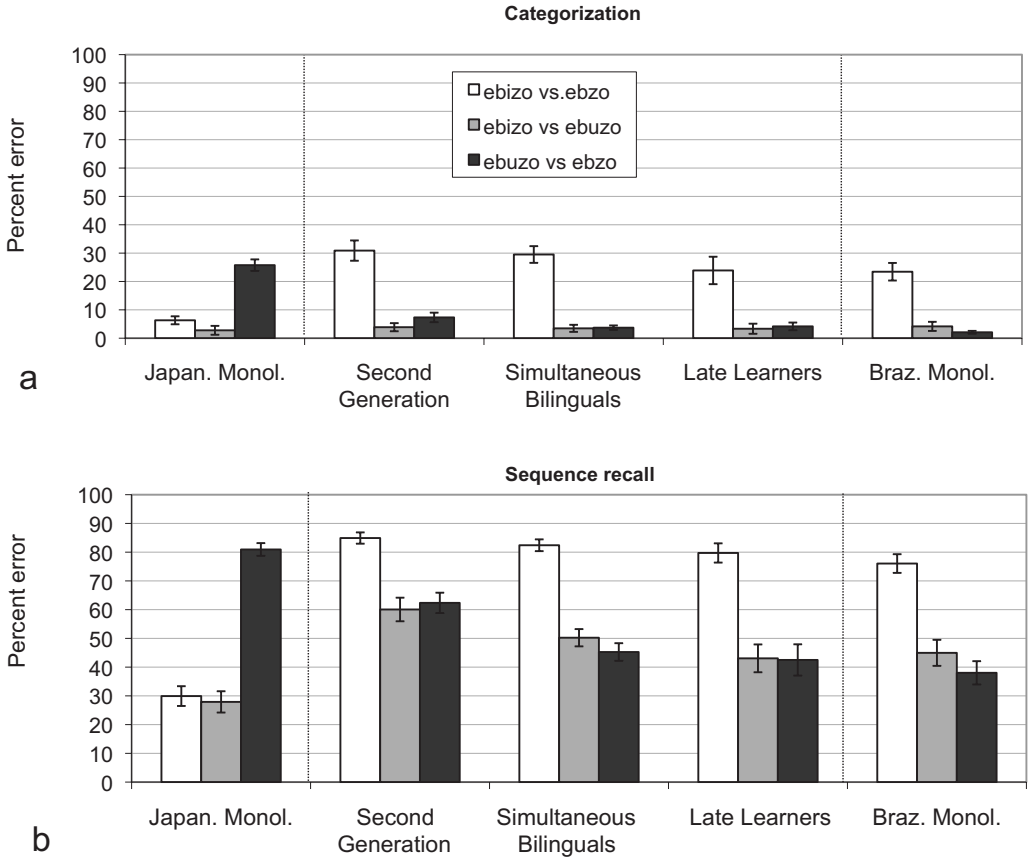

FIG. 2. Percent error in forced-choice categorization (top panel) or sequence recall (bottom panel), with minimal pairs of stimuli involving the presence or absence of the vowel /i/ (ebina versus ebna), the contrast between /i/ versus /u/ (ebina versus ebuna), or the presence or absence of the vowel /u/ (ebuna versus ebna), in five populations of participants with varying degrees of exposure to Japanese and Brazilian Portuguese.

ing to the stimuli: The computer started to record key presses only after the end of the word Okay). They had to respond by pressing the computer keys: For instance, if they heard agino-aguno-agino-agino, they had to respond with 2-1-2-2. Each trial was counted as correct if the whole sequence was correctly reported, and as incorrect if there was one or several errors in the sequence reported. A given trial could not count as two errors. Participants continued to receive feedback during this phase.

B. Results

The results of the categorization and the sequence recall test phases are shown in Figs. 2(a) and 2(b), and were analyzed separately.

For the categorization phase, we ran an ANOVA on the error rates with population as a between-participant factor (five modalities, three groups of bilinguals, and two control groups of monolinguals), condition as a within-participant factor (three modalities: ebuna/ebina, ebna/ebuna, and ebna/ebina), and order of presentation as a between-participant counterbalancing factor. We found a significant effect of condition $[F(2,266)=125.2,\ p<0.00001]$, no significant effect of population $[F(4,133)=1.3,\ p>0.1]$, and a significant interaction between condition and population $[F(8,266)=28.4,\ p<0.00001]$, reflecting the fact that different conditions triggered different error rates in different populations.

An inspection of Fig. 2(a) shows that the monolingual groups behaved as expected: For Brazilian monolinguals (right-most group of 3 bars), the ebna/ebina condition (white bar) was much harder than the other two, whereas for Japanese monolinguals (left-most group of 3 bars), it was the ebna/ebuna condition (black bar) that was much harder than the other two. To confirm this pattern of data, we ran an ANOVA with only two populations, which are the two monolingual groups. This ANOVA uncovered a significant interaction between population and condition $[F(2,110)=75.4,\ p<0.00001]$. Visual examination of the behavior of the bilingual groups shows that they all exhibit the same pattern as the Brazilian monolinguals, with a high error rate for the ebna-ebina condition, and a very low error rate for the other two conditions. To assess the statistical significance of this pattern, we tested the interactions between each of the bilingual and monolingual groups. Since there were six of such comparisons, we used a Bonferroni correction and multiplied all p-values by 6. We found that the Japanese monolinguals were significantly different from each of the three bilingual populations (all three $p<0.001$), and that the Brazilian monolinguals did not differ from any of them (all three $p>0.1$).

For the sequence recall task (see Fig. 2(b)), we ran an ANOVA on the percentage of errors, using the same factors as above: Population with five modalities, condition with three modalities, and the counterbalancing factor order of

presentation (two modalities). We observed a significant effect of condition [$F(2,266)=111.7$, $p<0.00001$], a significant effect of population [$F(4,133)=10.37$, $p<0.00001$], and a significant interaction between condition and population [$F(8,266)=69.6$, $p<0.00001$]. As in the categorization task, the ebna/ebina condition was harder than the control for Brazilian monolinguals, and the ebna/ebuna condition was harder than the control for Japanese monolinguals, with a significant interaction between condition and population in an ANOVA restricted to these two populations [$F(2,110)=147.0$, $p<0.00001$]. Just as in the categorization task, all three groups of bilinguals showed the same pattern of errors as the Brazilian monolinguals. This was confirmed by testing six interactions between condition and population (two modalities, one bilingual versus one monolingual), and Bonferroni-correcting them by multiplying all p-values by 6. These ANOVAs revealed that the Japanese monolingual population was different from all three of the bilingual populations (all three $p<0.001$), and that the Brazilian monolinguals did not differ from any of them (all three $p>0.1$).[2]

C. Discussion

In this experiment, we observed as in experiment 1 that monolingual Japanese listeners perceive an epenthetic /u/ vowel, when hearing an illegal consonant cluster, while monolingual Brazilian Portuguese listeners perceive an epenthetic /i/ vowel with the same stimuli. This was evidenced, here, by the greater confusability between ebna and ebuna for Japanese listeners, and the greater confusability between ebna and ebina for Brazilian Portuguese listeners, both in the categorization and in the sequence recall task. The behavior of bilingual participants was extremely clear-cut: All three groups of bilinguals behaved exactly like Brazilian monolinguals, showing high confusability between ebna and ebina, while the distinction between ebna and ebuna proved easy for them.

The difference between the present results and those of experiment 1 suggests that the task used in experiment 1 was more susceptible to the use of metalinguistic strategies, as we had suspected. Thus, in experiment 1, all groups of bilingual participants appeared to be aware that the non-preferred vowel was a valid possibility (since it was chosen at least 20% of the time by all groups of bilinguals). In addition, the behavior of the students of Japanese, who selected the /u/ vowel specific of Japanese about as often as the /i/ vowel specific of Brazilian Portuguese in the identification task of experiment 1, may be due to the fact that they became aware that /u/ is used in Japanese. In contrast, in experiment 2, participants were not asked to segment a stimulus into discrete linguistic/orthographic labels, but were put into a forced-choice procedure, featuring two nonwords presented as wholes (ebna/ebina or ebna/ebuna). In these circumstances, and in the presence of acoustic variability (since six different speakers were used), we observed that bilingual participants did not differ from monolinguals. In other words, the apparent influence of the non-dominant language that was reported in experiment 1 disappeared. This is consistent with the claim that implicit tasks are better than explicit tasks to uncover the format of the phonological representations encoded during on-line processing. The fact that identical response profiles were found in the categorization and sequence recall tasks (with sequences of four nonwords) shows that it is not always necessary to load the short-term memory of participants to eliminate the contribution of metalinguistic response strategies.

In brief, the results from this experiment show that with respect to the choice of the epenthetic vowel, the main variable is not the native language: Bilinguals from second generation, who heard only Japanese until they were 4–8 years old, nevertheless behaved just like Brazilian monolinguals.

IV. GENERAL DISCUSSION

In two experiments, one using an explicit vowel identification task, and one using implicit sequence recall tasks, we studied the perceptual epenthesis effect, i.e., the illusory perception of a nonexistent vowel within an illegal sequence of consonants, in several groups of Japanese-Brazilian Portuguese bilinguals. Our results can be summarized in three key findings.

The first finding comes from the behavior of early learners of Brazilian Portuguese, i.e., second-generation immigrants and simultaneous bilinguals. Second-generation Japanese immigrants were exposed only to Japanese from 0 to 4 years of life, acquired Brazilian when they entered the school system, and were mostly exposed to Brazilian Portuguese throughout their adolescence and adulthood. Simultaneous Japanese-Brazilian bilinguals from mixed families were exposed to both languages from birth. Both populations of participants appear to process illegal sequences of consonants like native Brazilian listeners, and unlike native Japanese listeners: For them, the epenthetic vowel is /i/ rather than /u/. These results are very comparable to those of Ventureyra *et al.* (2004), who showed that in adopted children, the native language can be replaced by a secondary language acquired during childhood. In contrast, our results are at odds with those of Pallier *et al.* (1997), who found that the native language blocked the acquisition of a secondary language in early learners of Catalan. What is counterintuitive here is that the population of second-generation immigrants is superficially more similar to the Spanish-Catalan early bilinguals of Pallier *et al.* (1997) than to the Korean adopted children of Ventureyra *et al.* (2004). Why can a native language phonology be "replaced" in some cases and not others? We come back to this issue below.

The second finding concerns the two populations of late learners, i.e., the first-generation immigrants and the students of Japanese. The first-generation Japanese immigrants could only be tested in the first experiment, and were very similar to Japanese monolinguals, despite the fact that they had been living more than 35 years in Brazil. This is consistent with findings showing limits in the plasticity of phonological representations for languages learned after puberty (Flege *et al.*, 1999b; Logan *et al.*, 1991; Dupoux *et al.* 2008). For native Brazilians who are students of Japanese, however, the picture is more complicated and depends on the task. In experiment 1, using an explicit task, these subjects had a pattern inter-

mediate between the Japanese and the Brazilian patterns, and reported /i/ epenthesis as often as /u/ epenthesis. This was due to a Japanese pattern emerging only for those subjects who had been exposed to Japanese before age 15. However, when tested with the implicit task of experiment 2, these subjects, irrespective of their earlier exposure to Japanese turned out to be indistinguishable from Brazilian monolinguals. If we judge that the implicit task gives a better estimate of on-line phonological encoding, then the results are that the late learners stick to their native phonology with little or no influence from the late-acquired language, except for metalinguistic judgments.

Our third finding regards the effect of tasks. In all our bilingual populations, we found an influence of the non-dominant language pattern for the explicit task used in experiment 1, but not for the more implicit tasks used in experiment 2. Our interpretation is that implicit tasks reflect relatively directly the encoding of speech sounds into phonological representations, whereas explicit tasks are, in addition, sensitive to metalinguistic skills (like segmentation of continuous strings into linguistic labels). Importantly, these two types of processing systems are not equally sensitive to experience with a non-dominant language: Phonological encoding seems to be done primarily in terms of a single, dominant language, whereas metalinguistic skills are more sensitive to the other languages. This has important methodological consequences for the study of plasticity in second language acquisition (see Dupoux *et al.*, 2008 and Werker and Tees, 1984b).

Regarding our paradoxical results with early learners and the comparison with the studies of Ventureyra *et al.* (2004), Pallier *et al.* (1997), and Oh *et al.* (2003), we can point to two sources of explanations for such discrepant results.

First, the methodology across these studies is markedly different, using a variable mix of on-line and off-line measures, perceptions, and production tasks. Oh *et al.* (2003) assessed phonology through a three-way forced-choice using printed words. Ventureyra *et al.* (2004) used an AX discrimination task. The case of Spanish-Catalan bilinguals is perhaps the best documented: Pallier *et al.* (1997) used a forced-choice categorization task and an AX discrimination task, and Pallier *et al.* (2001) used speeded lexical decision; Sebastián-Gallés and Soto-Faraco (1999) used a gated forced-choice nonword classification task. Apart from the study by Oh *et al.* (2003), these studies all include some version of an implicit measure of perception (i.e., one that does not make explicit reference to linguistic segments). In this respect they are comparable to our experiment 2, so that we can be relatively confident that the overall divergent pattern is not due solely to issues related to metalinguistic access.

Second, the sociolinguistic status of the native and non-native languages within the environment of the child is markedly different across the three studies and ours. Ventureyra *et al.* (2004) presented the most extreme case, since not only the native language but also all of the native culture simply disappeared from the environment of the adopted children. In the present study, the Japanese language and culture remained present in the second-generation immigrants' environment in Brazil, but the pressure to abandon them was strong. As documented in Sec. II A, Japanese was politically suppressed in Brazil, was made illegal during WWII, and was not promoted in schools. Significantly, some of our second-generation subjects even denied speaking Japanese. Regarding the Oh *et al.* (2003) study, Korean probably had a better status in the US, which is generally speaking rather tolerant for community-specific cultures and languages, even though English remains the only official language. Yet, ethnographic studies show that once children use predominantly English, they rarely interact with those of their relatives that speak little or no English (Fillmore, 1991; Kouritzin, 1999), suggesting a social pressure to stick to the default language of the environment. Finally, in the Pallier *et al.* (1997) study, Spanish, which is the native language, is the default official language of the country. It is the nonnative language, Catalan, that used to be in danger of disappearing. Because of the large political efforts made since 1960 to restore Catalan, nowadays, in Barcelona, both languages are used in everyday life. In brief, even though the pressure to learn Catalan is large for Spanish families living in Catalunia, there is no pressure to abandon Spanish.

This ordering of the sociolinguistic status of the native language meshes well with the empirical evidence: Total loss of the native language for the adopted Korean, almost total switch to the second language for second-generation Japanese immigrants, switch to the second language with traces of the native language for Korean immigrants, and no switch to the second language for Spanish second-generation immigrants in Catalonia. It also meshes well with several sociolinguistic studies, which claim that the choice of the dominant language within a bilingual community is heavily influenced by the relative status of the languages and the pressure for cultural assimilation (Grosjean, 1982; Fishman, 1991). As a result, it is possible that the perceptual effects measured here are direct reflections of the pressure to adopt the dominant language. This would suggest that sociolinguistic forces can heavily shape the tuning of our perceptual apparatus, to a degree not envisioned by previous studies, that were emphasizing instead the role of the parent-child interactions (language of the mother, role of motherese, etc.).[3]

To sum up, our study confirms the study of Ventureyra *et al.* (2004), namely, the fact that is it possible, during childhood, to remap the phonological processing from the native language to a foreign language, at least in part. Such plasticity would extend beyond 4 years of age and possibly exist throughout childhood. However, it does not extend to adulthood, since late learners, unlike early learners, kept their native phonological system. We also point out that our results are congruent with much sociolinguistic work, suggesting that this remapping takes into account the sociological importance of each of the two languages during childhood. Such conclusions need to be further buttressed by a better measure of sociolinguistic factors, and a more homogeneous use of implicit on-line tasks.

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APPENDIX

Acoustic analysis of the experimental stimuli from experiments 1 and 2 [mean (standard error of the mean)]. Note that the standard errors are high for the F0 values of experiment 2, because male and female speakers were mixed.

	First vowel *e*	First consonant *b*	Middle vowel *i*	Second consonant *n*	Last vowel *a*
Experiment 1: ($n=13$)					
Duration (ms)	86(2.3)	115(3.7)	-	110(4.3)	189(7.9)
Max F0 (Hz)	138(2.3)	130(2.0)	-	155(4.4)	163(2.1)
Experiment 2: Stimuli without a middle vowel ($n=12$)					
Duration (ms)	61(3.7)	81(7.7)	-	70(6.1)	111(5.5)
Max F0 (Hz)	232(18.0)	230(18.0)	-	191(11.2)	176(10.6)
Experiment 2: Stimuli with a middle vowel ($n=24$)					
Duration (ms)	59(3.1)	56(1.8)	57 (1.9)	57(2.3)	92(5.8)
Max F0 (Hz)	227(12.0)	223(11.6)	207 (8.4)	194(8.0)	176(7.9)

[1]Since we tested successive generations of Japanese immigrants in Brazil, and that Japanese immigration in Brazil was fairly limited historically, it was not technically possible to match the age across groups. However, given that our task was not loaded in executive functions and was not speeded, there is no reason to expect differences in performance as a function of age. Even if it did, our analysis did not focus on absolute percentages, but rather on the difference between /i/ and /u/ responses, which then should be relatively invariant with age.

[2]To compare with the analysis ran in experiment 1, we computed a correlation between prior exposure to Japanese and the ebna/ebina versus ebna/ebuna difference score, for the students of Japanese group [$R=-0.44$, $F(1,13)=3.2$, $p=0.095$, and $R=-0.099$, $F(1,13)<1$, $p>0.1$ for the categorization and sequence recall tasks, respectively]. Contrary to experiment 1, it was not significant, and all students of Japanese behaved like Brazilian Portuguese monolinguals, irrespective of whether they had been exposed to Japanese in late childhood or not.

[3]This conclusion should be mitigated by two considerations. First, it is unlikely that sociolinguistic forces per se are the direct cause of the present pattern of results. It is more likely that sociolinguistic forces induce a change in amount of language usage, and that it is the amount of language use which causes changes in phonological representations. Second, as we suggested, sociolinguistic factors may well play a significant role during childhood, but not in adults who are acquiring a new language from scratch. In other words, age of acquisition remains a very important factor.

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