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Phonetic *vs.* phonological influences on French listeners' perception of American English approximants

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The perception of American English (AE) approximant contrasts, /r/-/l/ in particular but also /w/-/r/ and /w/-/j/, has been extensively compared between AE speakers and speakers of Japanese or other languages lacking an /r/-/l/ contrast. The difficulty such listeners encounter with the AE /r/-/l/ contrast, especially those who have had little exposure to spoken English, has most often been explained by reference to the abstract functional contrasts of their native phonological systems, which lack distinctions between rhotic (/r/) and lateral (/l/) consonants. According to that reasoning, speakers of languages who *do* possess an /r/-/l/ distinction, such as French, should encounter little or no perceptual difficulty with AE /r/-/l/. However, French and AE /r/s differ markedly in their articulatory-phonetic characteristics, which suggests the possibility that French listeners might have some difficulty categorizing AE /r/. The present study therefore examined identification and discrimination of the AE continua /r/-/l/, /w/-/r/, and /w/-/j/ by French participants. As anticipated on the basis of the phonetic differences between the /r/s of the two languages, the French listeners had some perceptual difficulties with AE /r/, which they tended to assimilate as /w/-like. We conclude that the detailed articulatory-phonetic properties of the native versus non-native consonant categories, rather than solely the abstract phonological contrasts of the two languages, account for this perceptual pattern. © 1999 Academic Press

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1. Introduction

Perception of speech segments by adults is highly constrained by their experience with the phonological properties of their native language. Empirical observations of the performance limitations these constraints impose on both perception and production of non-native consonants and vowels can be traced back at least to the 1930s (Polivanov, 1931; Trubetzkoy, 1939/1969). These early reports offered an apt metaphor for the presumed source of the difficulties, located in the linguistic structure of the native language — the notion that mature speaker-hearers possess a language-specific "phonological filter" through which non-native phones must pass. That is, unfamiliar phones get funneled through the framework of phonological contrasts employed by the native language, causing distinctions that are not employed contrastively in the listener's language to be difficult to discriminate and produce.

Numerous subsequent findings on perception of non-native speech contrasts have been consistent with those early observations. A classic example of perceptual constraints imposed by the native system of phonological contrasts comes from investigations of the English /r/-/l/ contrast as heard by listeners whose language lacks a rhotic (/r/) *vs.* lateral (/l/) phonological contrast. Perception of English /r/-/l/ has been extensively studied in Japanese-speaking adults with varying degrees of English proficiency (Miyawaki, Strange, Verbrugge, Liberman, Jenkins & Fujimura, 1975; MacKain, Best & Strange, 1981; Mochizuki, 1981; Sheldon & Strange, 1982; Underbakke, Polka, Gottfried & Strange, 1998; Best & Strange, 1992; Yamada & Tohkura, 1992; Takagi & Mann, 1995; Brown, 1996). Japanese listeners who have had little conversational experience with native English speakers tend to discriminate /r/-/l/ poorly, a fact that has traditionally been explained by the crucial phonological difference between the two languages (e.g., Goto, 1971; Miyawaki et al., 1975; MacKain et al., 1981; Brown, 1996; see also Sato, 1984; Broselow & Finer, 1991; Eckman & Iverson, 1993): whereas English maintains a phonological contrast between /r/ and /l/, Japanese lacks an /r/-/l/ contrast because it employs an /r/ but no /l/. Similar results have been obtained with speakers of other languages lacking an /r/-/l/ contrast (Korean: Gillette, 1980; Ingram & Park, 1998; Cantonese: Henly & Sheldon, 1986). More generally, speakers of a wide range of languages have difficulties perceiving non-native distinctions that do not correspond to any native phonological contrast (Abramson & Lisker, 1970; Werker, Gilbert, Humphrey & Tees, 1981; Flege, 1984; Flege & Eefting, 1986, 1987; Jamieson & Morosan, 1986; Polka, 1991, 1992).

The apparent generality of these difficulties in discriminating non-native contrasts has motivated various attempts, over the past two decades of cross-language research, to elucidate the processes by which language experience adjusts speech perception along the lines of the listener's native phonological system. A central premise that has emerged from this research is that perceptual attunement to native speech does not occur solely at the phonological level, i.e., only with respect to abstract contrastive functions and phonological rules. It is necessarily responsive to the specific phonetic details of native *vs.* non-native segments as well (e.g., Mochizuku, 1981; Polka & Strange, 1985; Mann, 1986; Underbakke et al., 1988; Takagi & Mann, 1995). To evaluate that notion, researchers have examined not only non-native distinctions that are absent in the listener's native language as phonological contrasts, but also non-native phones that differ phonetically from the phonologically equivalent native segments (e.g., Abramson & Lisker, 1970; Best & Strange, 1992; cf. Ingram & Park, 1998).

Similarly, research has shown that perception of a given non-native contrast can vary considerably across phonetic contexts (Sheldon & Strange, 1982; Lively, Logan & Pisoni, 1993), and across listener groups from different language communities (Henly & Sheldon, 1986). These findings cast strong doubt on the adequacy of the traditional phonological view alone to account for all aspects of non-native speech perception.

Several theoretical models have been developed to address the premise that non-native speech perception reflects not only the abstract phonological properties, but also the phonetic details, of the native language. The Perceptual Assimilation Model (PAM: Best, McRoberts & Sithole, 1988; Best, 1994, 1995) posits that listeners' perceptual assimilation of non-native phones to the native phonological system depends not only on which contrasts occur in the native language, but also on the phonetic-articulatory similarities (and dissimilarities) between the non-native items and native phonological categories. Similarly, the Speech Learning Model (SLM: Flege, 1986, 1991, 1995) proposes that adult learners of a second language (L2) use equivalence classification to relate non-native phones to their own native (L1) phonological categories. The Native Language Magnet model (NLM: Kuhl, 1991; Kuhl, Williams, Lacerda, Stevens & Lindblom, 1992; Iverson & Kuhl, 1995, 1996) proposes that perception of phonetic variation within native phonological categories is systematically organized along certain acoustic dimensions, determined by language-specific experience, such that discrimination is poorer in the neighborhood of a category's "ideal" exemplar, or prototype, than in the neighborhood of non-prototypes of the same category (see also Volaitis & Miller, 1992; Miller, 1994; Hodgson & Miller, 1996).

To directly compare how both phonetic details and phonological contrasts in the L1 affect non-native speech perception, Best & Strange (1992) compared Japanese and American English (AE) listeners' categorical perception of synthetic continua for the AE approximant contrasts /r/-/l/, /w/-/r/ and /w/-/j/; only the latter two pairs constitute phonological contrasts in Japanese. The rationale focused on the phonetic-articulatory differences of /w j r/ between the two languages. Japanese has no /l/; phonologically speaking, its /r/ is of the type "rhotic" within the class "liquid" (see Lindau, 1985; Ladefoged & Maddieson, 1995). However, the phonetic differences between the /r/s of the two languages are striking. Japanese /r/ is usually realized as an alveolar tap [ɾ] (Bloch, 1950; Vance, 1987), though the actual realization is modulated by phonetic and phonotactic context. It is rarely produced like AE /r/, which also varies in pronunciation but is most commonly produced as a frictionless palato-velar central approximant [ɹ] with secondary pharyngeal constriction (so called "bunched /r/"), or less frequently as a retroflex approximant [ɻ] (Delattre & Freeman, 1968; Zawadzki & Kuehn, 1980; Boyce & Espy-Wilson, 1997). In addition, both AE /w/ and /r/ are lip-rounded, and differ in tongue dorsum (/w/) *vs.* tongue blade + pharynx (/r/) constrictions; neither is a perfect fit to the unrounded Japanese /w/ ([ɰ]) (Bloch, 1950; Vance, 1987), though AE /w/ is closer in terms of tongue constriction location.

The Japanese listeners showed inconsistent categorization and poor discrimination of /r/-/l/, compatible with previous reports. Although Japanese spellings of English loan-words tend to represent both AE /r/ and /l/ as Japanese /r/ (e.g., English "realism" > Japanese/ri'arizumu/), the performance of inexperienced Japanese listeners (with respect to spoken English) suggested that neither AE phoneme was a very good example of their tapped /r/. Labeling and discrimination of the /w/-/r/ continuum was much better, but still somewhat below the levels for AE listeners, suggesting that neither AE /r/ nor AE /w/ was perceived as an ideal example of the corresponding Japanese phoneme.

That study, as well as the one by Yamada & Tohkura (1992), provided evidence that native Japanese listeners perceive AE /r/ as somewhat /w/-like. Whereas other authors have reported that AE /r/ is instead perceived as a poor Japanese /r/ (Flege, Takagi & Mann, 1996; Takagi, 1995; Yamasaki, pers. comm.), these claims are not necessarily incompatible — AE /r/ might sound like a poor native /r/ to Japanese listeners because they detect some modest (i.e., sub-phonemic) /w/-like properties. Notably, the studies reporting Japanese perception of /w/-like properties in AE /r/ employed categorical perception tests with synthetic continua (Best & Strange, 1992; Yamada & Tokhura, 1992), while those reporting assimilation of AE /r/ to (poor) Japanese /r/ used natural contrasting-category stimuli (Flege et al., 1996; Takagi, 1995; Yamasaki, pers. comm.). Possibly, categorical perception procedures, which employ systematic, fine-grained variations among synthetic stimuli, may be better suited to reveal listener sensitivity to within-category phonetic variations (reflected as group differences in boundary locations, slopes, or within-category performance levels).

The Japanese listeners in Best & Strange (1992) appeared to have assimilated /w/-/j/ as a native phonological contrast. However, a clear double peak in their discrimination function strongly suggested a third intervening perceptual category between /w/ and /j/, similar to that of the American listeners, who identified the third category as /l/. Given Japanese loanword phonology, the intervening category that Americans heard as /l/ may be perceived by the Japanese as similar to their tapped /r/, which would add converging support to the notion that their difficulty with AE /r/-/l/ lies in the phonetic similarity of these sounds within the framework of spoken Japanese.

Best & Strange (1992) concluded that perception of unfamiliar non-native speech contrasts is based not only on the abstract functional properties of the native phonological system, but even more fundamentally on phonetic-articulatory relations between the most similar native and non-native phones. This suggestion could be evaluated more directly, however, by examining the perception of AE /r/-/l/ by listeners whose native language does have a parallel phonological contrast, but for which the phonetic details are notably discrepant from the English ones. Such cases have received little empirical attention. For comparison with the earlier American and Japanese findings (Best & Strange, 1992), the language should also employ /w/-/r/ and /r/-/j/ as phonological contrasts. These conditions are met by French, whose /r l w j/ differ from AE not in their abstract phonological structure, but rather in their phonetic-articulatory details. The present study tested native French listeners to evaluate the perceptual influences of phonetic-articulatory *vs.* phonological correspondences between non-native and native phonemes. For this first investigation, we elected to test categorical perception (CP) of the synthetic AE /r l w j/ continua used by Best & Strange (1992), employing the same testing procedures. One reason for choosing this option was that our study focused on the *possibility* that French listeners might have some perceptual difficulty in processing AE /r/. That difficulty could be, *prima facie*, a small one. Thus, we needed a procedure whereby subtle difficulties could be detected. In that respect, the use of synthetic continua and CP tests is appropriate because they can reveal fine-grained variations in accuracy and sensitivity. By comparison, identification and discrimination using categorically-differing natural tokens might fail to reveal such modest deficits. That is, synthetic stimuli are actually more apt than natural, ecological stimuli to capture behavioral differences that may be subtle. Moreover, using the same continua as Best & Strange (1992) not only offered a sensitive measure of French listeners' perception of systematic within-category phonetic variation, but also allowed for direct comparisons against their findings.

In both French and English, /r/-/l/ is a phonological contrast between a rhotic and a lateral consonant, which is referred to as a *liquid* contrast in classic phonological terms (Lindau, 1985; Ladefoged & Maddieson, 1995). As these authors note, there is a wide range of variation in language-specific phonetic realizations of these consonants, particularly the rhotics (which include not only approximants and vowels, but also taps, flaps, fricatives, and trills at uvular and/or apical places of articulation). However, such phonetic details are "invisible" at the phonological level, which describes the abstract functional and structural relationships that exist among the segments employed in the sound system of a given language. Rhotics and laterals each participate as classes in phonological rules and behave similarly across languages, occupying similar positions in their consonant systems, syllable structures, phonotactic regularities, and allophonic and morphophonemic alternations (Lindau, 1985; Ladefoged & Maddieson, 1995). In other words, even though abstract phonological accounts cannot directly state that, for example, AE and French /r/-/l/ contrasts are phonologically identical (because phonological contrasts are definable only within a given language sound system), such accounts would consider these contrasts to be functionally "parallel."

Thus, the crucial *phonological* difference between Japanese, on the one hand, and French and AE on the other, is that Japanese uses a single liquid (/r/) whereas the other two languages employ a liquid phonological contrast (/r/-/l/). Language differences in the surface phonetic realizations of /r/ are irrelevant to this abstract phonological characterization. But it is precisely the cross-language differences in phonetic realizations that are central to the present study. French and English /l/ are relatively similar in articulatory-phonetic characteristics — both are approximants involving lateral branching of the airflow around the side(s) of the tongue. However, the French /l/ is realized with *dental* contact of the tongue tip and without raising of the tongue dorsum (i.e., "flat" tongue body) (Simon, 1967; Delattre, 1969, 1971*a*; Chafcouloff, 1972, 1979). AE /l/, on the other hand, involves *alveolar* contact, and includes some raising of the tongue dorsum in the velar region, not only for the "dark"/l/ ([ɫ]) found in syllable-final position but also for the so-called "light" /l/ ([l]) found in syllable-initial position (Giles & Moll, 1975; Hardcastle & Barry, 1989; Sproat & Fujimura, 1993; Recasens & Farnetani, 1994; Browman & Goldstein, 1995; Stone & Lundberg, 1996). The acoustic effect of the articulatory difference is that the dorsum constriction in AE /l/ lowers the frequency of the second and third formants ($F2$, $F3$) somewhat, bringing $F1$ and $F2$ closer together, relative to French /l/ (Lisker, 1957; O'Connor, Gerstman, Liberman, Delattre, & Copper, 1957; Chafcouloff, 1972; Hardcastle & Barry, 1989; Espy-Wilson, 1992; Recasens & Farnetani, 1994).

The phonetic-articulatory difference is much more striking between French and AE /r/s. The most common French /r/, particularly in the region including Paris, is an uvular approximant[1] that may be fricated to some degree especially when voiceless, and is voiced or voiceless according to syllable position and phonetic context ([ʁ] or [χ], respectively). Less commonly, and mostly in other regions of France, /r/ may be trilled at a uvular or apical place of articulation ([ʀ] or [r], respectively). The uvular forms of French /r/ typically involve a pharyngeal constriction (Delattre, 1969, 1971*b*), offering

[1]Standard French /r/ may be described as a fricative rather than an approximant. That distinction, however, is not crucial to the phonological *vs.* phonetic points we make: it is a rhotic or *r*-sound and hence is functionally equivalent to the AE /r/ at the abstract phonological level; conversely, it is phonetically quite discrepant from the AE /r/ regardless of the precise phonetic terms used.

perhaps some point of articulatory commonality with the AE /r/ (described earlier). However, the constriction location is high in the pharynx for French /r/, but quite low for AE /r/ (Delattre, 1971*b*). The primary distinguishing acoustic feature of AE /r/ is a low $F3$ frequency value, with a relatively steep transition into and/or out of the higher $F3$ frequency of most surrounding vowels. In contrast, French /r/ has small or nonexistent formant transitions, except in rounded vowel contexts (Chafcouloff, 1979), because $F3$ is high in uvular /r/s.[2] The constriction for French uvular /r/ causes a large reduction in energy and often a break in formant structure that may or may not be associated with frication (or trilling).

By comparison, /w/ and /j/ are much more similar in their articulatory and acoustic properties between AE and French. In both languages, these glide approximants are produced with smooth movements into and out of constrictions similar to /u/ and /i/, respectively. Given that AE /u/ is somewhat more fronted and perhaps shows less lip protrusion than French /u/, the AE /w/ may have slightly higher $F2$ and $F3$ values (Chafcouloff, 1979; Espy-Wilson, 1992).

From an abstract phonological viewpoint, French listeners should behave like the AE listeners in Best & Strange (1992), showing equivalent, highly categorical identification and discrimination on all three AE continua (/r/-/l/ = /r/-/w/ = /w/-/j/). Like AE listeners, French listeners should exceed the Japanese listeners' (Best & Strange, 1992) identification and discrimination performance on /w/-/r/ and especially on /r/-/l/, but not on /w/-/j/.

Phonetic-articulatory considerations, on the other hand, suggest a different pattern of French performance for contrasts involving AE /r/. Because the /r/s of the two languages are phonetically quite distant from one another, AE /r/ may not be assimilated unequivocally to French /r/, and certainly not as a good one. Indeed, the lip-rounded AE /r/ may show some phonetic similarity to French /w/, and therefore may show some perceptual bias toward French /w/. As a result, French listeners should show less categorical identification and discrimination of AE /w/-/r/ relative to AE listeners, but similar to that of Japanese listeners. By comparison, on AE /r/-/l/ French listeners should show less impaired performance relative to AE listeners, with substantially better performance than the Japanese, because they should hear AE /l/ as something categorically different from AE /r/, regardless of whether they assimilate the latter sound as a poor French /r/ or as something like a /w/. Finally, because AE /w/ and /j/ are nearly identical to French /w/ and /j/, respectively, French performance on /w/-/j/ should be categorical, parallelling that of both AE and Japanese listeners. That is, phonetic-articulatory considerations predict a French categorical perception pattern of /w/-/j/ > /r/-/l/ > /w/-/r/, in contrast to the previously observed Japanese pattern of /w/-/j/ > /w/-/r/ ≫ /r/-/l/ and AE pattern of /w/-/j/ = /r/-/l/ = /w/-/r/.

2. Experiment 1

2.1. *Method*

2.1.1 *Participants*

Fifteen French university students participated in this study (M = 22.8 years, range = 19–27 years). Twelve participants had lived most of their lives in the Ile de

[2]It is noteworthy that uvular /r/s are inconsistent with the proposition that the /r/s of the world's languages share the acoustic property "low $F3$", which appears to be the only single acoustic property potentially shared by non-uvular forms of /r/. Thus, there is no universal acoustic attribute shared by all /r/s (Lindau, 1985).

France region, which includes Paris. The other three grew up in the central, northeastern, or southwestern regions of France; their perceptual data were not noticeably different from the others. All reported little to no spoken English experience with native speakers of American or British English. Each reported low levels of current experience speaking and listening to English, and rated their oral–aural proficiency as poor to mediocre on a 1–5 self-rating scale (5 for very fluent), combined across oral–aural scores. For a possible maximum rating of 10, the final ratings of participants ranged from 2 to 6, yielding a mean rating of 3.8. None reported any hearing, speech, language, or reading acquisition problems in themselves or their immediate family. Five additional participants were tested but removed from the final data set, two for failing to complete all three tests, one for having lived 6 months in an English-speaking country (U.S.A.), one whose first language was Vietnamese, and one whose responses on all tests were near or at chance level. Participants were paid 50 francs per hour.

2.1.2. *Stimulus materials*

We used the /rak/-/lak/, /wak/-/jak/, and /wak/-/rak/ 10-step continua employed in MacKain *et al.* (1981) and Best & Strange (1992). These were 3-formant stimuli, generated on the OVE-IIIc cascade formant synthesizer at Haskins Laboratories except for the final /k/ burst, which was excised from natural speech and appended to the synthetic syllables. The endpoint and intermediate stimuli of all continua had been equated for the overall duration (330 ms including the burst of the final /k/), amplitude and $F0$ contour (rising-falling).

2.1.3. *Procedure*

The same procedures as in Best & Strange (1992) were used. Participants were run in three different sessions (at 2 or 3 days intervals), one for each continuum. Session order was randomized. In each session, participants first completed a two-choice identification test, then an AXB discrimination test of the same series. There was a 15 min break between the two tests. Participants were tested individually in a sound-attenuated booth. Stimuli were presented through Sennheiser HD 520 headphones via a Denon DTR-100P digital tape recorder at a comfortable listening level. After the completion of the two tests, participants completed a post-test questionnaire, including an informal description of the sounds they heard.

The identification tests consisted of 20 blocks of 10 trials, presented in random order. Each of the 10 stimuli was thus presented 20 times. The intertrial and interblock intervals were 2.5 s and 4 s, respectively. For each trial (listed by number on an answer sheet), the participants had to circle one of two letters (e.g., “W” and “Y” for the /w/-/j/ series) to indicate the initial consonant they heard.

The discrimination task was a three-step AXB procedure, as in Best & Strange (1992). Along each continuum were seven pairs of stimuli differing by three steps (1–4 to 7–10). Each pair was repeated 5 times for each possible AXB combination (AAB, ABB, BAA, and BBA), hence there was a total of 140 trials (four combinations × seven pairs × five repetitions). These 140 trials were presented in random order, in 14 blocks of 10 trials. The intertrial and interblock intervals were 3 s and 6 s respectively, and within-trial interstimulus intervals were 1 s. The participant had to circle the number “1” or the number “3” on the answer sheet for each trial to indicate whether the second item (X) matched the first or the third (last) item.

2.2. Results

2.2.1. *Identification*

The identification data are summarized in Fig. 1. The upper panels (A)–(C) display the French data obtained in the present study against the American data from the Best & Strange (1992) study. The lower panels (D)–(F) reproduce the Japanese data from the latter study. The pooled identification functions suggest that French listeners' performance was similar to that of American listeners especially for the /w/-/j/ series, and also for /r/-/l/. For the /w/-/r/ series, French listeners performed rather poorly as a group. They tended to perceive the AE /r/ as being somewhat similar to French /w/. This claim is supported by the location of the category boundary, which is shifted toward /r/ compared to American listeners (i.e., the French identified *fewer* "R"s than Americans). It is also supported by the relatively high percentage of /w/ judgments at the /r/ endpoint of the continuum (more than 27% for all participants pooled).

These observations were substantiated by statistical analyses. In order to compare French listeners' categorization of the three continua with the performance of the American and Japanese listeners from the Best & Strange study, best fit ogives of individual participants' identification functions were estimated by using narrow-range PROBIT analyses, as was done in Best & Strange (1992). This procedure allows for a reliable estimate of an individual listener's category boundary location — the 50% intercept of the ogive — and the precision of the boundary, as expressed by the steepness, or slope, of the ogive at the boundary, provided there is a good fit between the ogives and the raw data.[3] Boundary location and boundary precision are, respectively, μ and $1/\sigma$ of the fitted cumulative Gaussian normal function.[4] The results for the three listener groups are summarized in Tables I (locations) and II (slopes). Note that the boundary locations and slopes computed for each individual, then averaged by listener group, reliably describe the identification performance, whereas pooled identification functions can sometimes be misleading because of possible individual variations. Boundary location and slope could not be computed for five participants on the /w/-/r/ continuum because boundary location fell outside the [1, 10] range of stimulus numbers. Indeed, these five participants predominantly responsed "W" throughout the continuum (the "W-dominant" subgroup); one gave 100% /w/ responses for all the stimuli.

The location and slope data for the French participants in the present study and for the Americans and the Japanese in Best & Strange's study[5] were entered in

[3]This procedure fits a cumulative normal curve to the raw data. Only three data points are used provided they encompass the 50% crossover. These points generally correspond to contiguous stimulus numbers. The result is a smoothed identification function that is referred to as a narrow-range ogive fit function (see Best & Strange, 1992).

[4]The narrow-range ogives generally fit well with the raw data. This was assessed by χ^2 tests (see Best & Strange, 1992). For the /w/-/j/ and /r/-/l/ series, all of the 30 χ^2 values computed for the French participants were non-significant. For the /w/-/r/ series, in which narrow-range ogive fitting could be computed for only 10 participants, the χ^2 values were likewise non-significant. Hence, the narrow-range ogives provided a good fit to the raw data.

[5]The comparison between the French data and the American and Japanese data of the Best & Strange (1992) study could have been based simply on *t*-tests, using the means, standard deviations, and number of observations reported in the Best and Strange study. However, because a slightly different fitting algorithm was used in the present study, intercepts and slopes for the Best & Strange (1992) raw data were recomputed using our algorithm, which yielded very similar intercept values, and somewhat smaller slope values, as can be seen by comparing Tables I and II of this study with Tables II and III of Best & Strange.

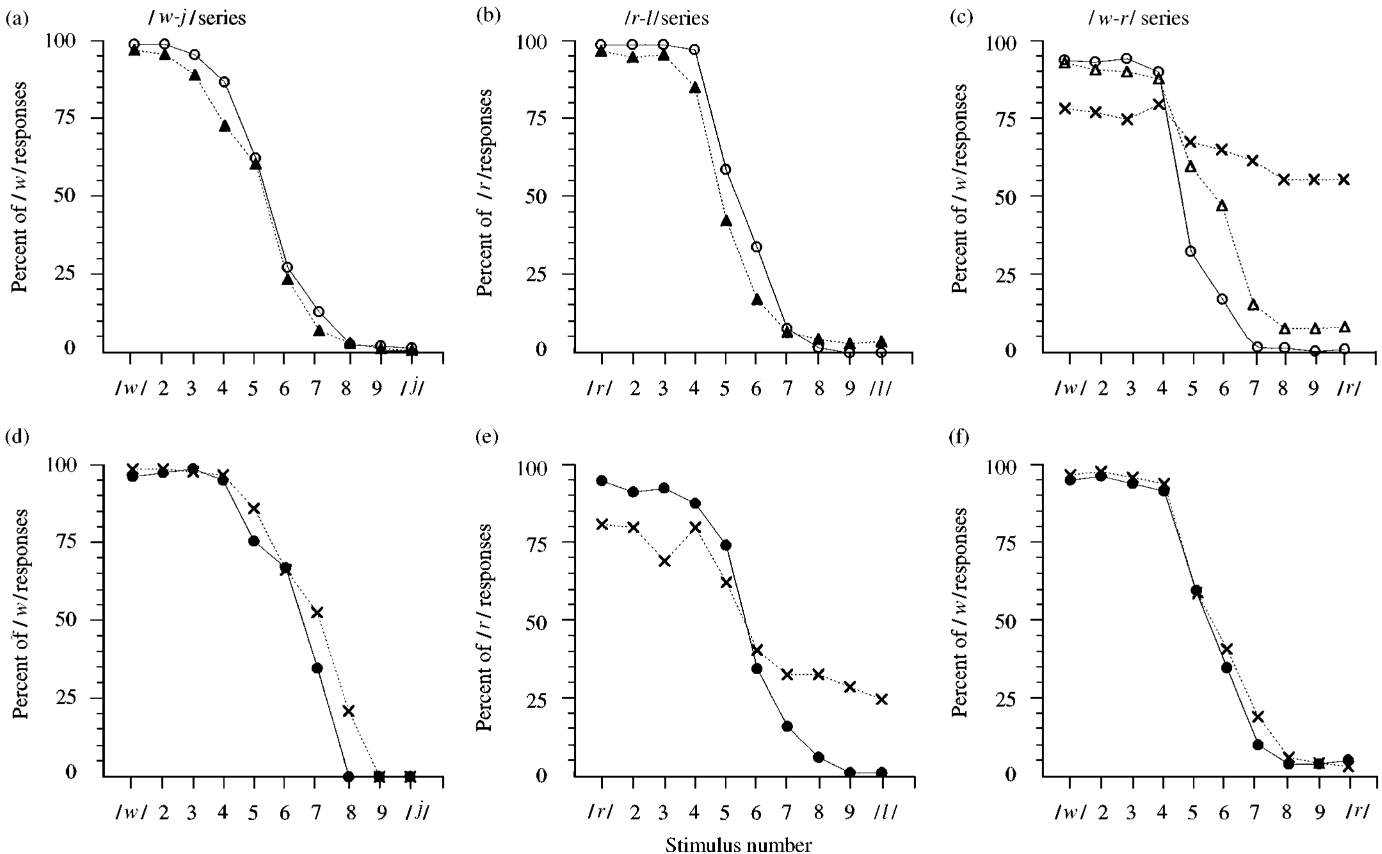

Figure 1. Identification functions for the /w-j/, /r-l/, and /w-r/ series. Upper panel: Americans and French. The French data are pooled ((a) and (b)) or partitioned (c) into two-category and W-dominant participants for the /w-r/ series. Lower panel: experienced and inexperienced Japanese. The American and Japanese data are from the Best & Strange (1992) Experiment 1; the French data are from the present study, Experiment 1. (For panels (a)–(c): ——○—— Americans; ——▲—— French (pooled); ——△—— two-category French; ——×—— W-dominant French; for panels (d)–(f): ——●—— experienced Japanese; ——×—— inexperienced Japanese.)

TABLE I. Boundary locations for French, American, and Japanese listeners: means and standard deviations. The numerical values represent stimulus numbers along the continua (from 1 to 10). Stimulus #1 is always the first endpoint of a series (e.g., stimulus #1 is /w/ in the /w-j/ series)

	/w-j/			/r-l/			/w-r/		
	N	*M*	*SD*	N	*M*	*SD*	N	*M*	*SD*
French	15	4.85	(1.29)	15	4.88	(0.81)	10	5.68	(0.62)
Americans	9	5.36	(1.06)	9	5.38	(1.01)	9	4.84	(0.70)
Japanese (pooled)	9	6.54	(1.15)	9	6.15	(1.45)	9	5.61	(0.76)
Experienced	4	6.37	(1.19)	4	5.60	(0.74)	4	5.42	(0.71)
Inexperienced	5	6.68	(1.23)	5	6.60	(1.80)	5	5.76	(0.84)

TABLE II. Identification precision for French, American, and Japanese listeners: means and standard deviations. The numerical values represent rates of percentage change in category response per step (see text for more details)

	/w-j/			/r-l/			/w-r/		
	N	*M*	*SD*	N	*M*	*SD*	N	*M*	*SD*
French	15	1.77	(0.59)	15	1.53	(0.43)	10	1.02	(0.45)
Americans	9	1.93	(1.03)	9	2.15	(0.73)	9	1.72	(0.69)
Japanese (pooled)	9	1.67	(0.81)	9	0.92	(0.92)	9	1.11	(0.58)
Experienced	4	1.67	(0.73)	4	1.49	(1.14)	4	1.25	(0.61)
Inexperienced	5	1.66	(0.96)	5	0.46	(0.37)	5	1.00	(0.60)

Group × Series ANOVAs.[6] For boundary locations, Group had a significant effect, $F(3, 24) = 6.47$, $p = 0.0024$, but Series did not. For slopes, both Group and Series had a significant effect, $F(3, 24) = 7.64$, $p = 0.001$, and $F(2, 48) = 3.63$, $p = 0.033$, respectively. The Group × Series interaction was not significant, for either locations or slopes.

Planned comparisons were run to compare the French with the Americans and the French with the Japanese. The French did not differ significantly from the Americans on the /w/-/j/ continuum, for either boundary location (around stimulus 5) or precision (∼1.8). For the /r/-/l/ continuum, French and American listeners exhibited similar boundary locations, but Americans had significantly steeper identification function (2.15 *vs.* 1.53), $F(1, 22) = 6.93$, $p = 0.015$. For the /w/-/r/ continuum, French listeners' performance differed sharply from that of Americans in two ways. First, the data of five French participants could not be analyzed in terms of the narrow range ogive fit because of their "W-dominant" pattern of responses. Second, the data of the 10 remaining "two-category" French participants differed from that of American listeners for boundary

[6]The Groups were inexperienced and experienced Japanese, American, and French listeners. Because the /w/-/r/ series data of five French participants were missing, due to the absence of within-continuum intercepts in their data for /w/-/r/, we first ran two separate ANOVAs, one using the two /w-j/ and /r-l/ series with all the 15 French participants, and the other using only the /w-r/ series with the 10 French participants for whom location and slope could be computed. We also ran a third ANOVA using all three series, with only the 10 latter French participants, in order to estimate the effects of Group and Series in a full-design analysis. The main effects found in these ANOVAs were the same. The global effects of Group and Series, as well as the interaction between these two variables are as computed with the full-design ANOVA. The detailed comparisons between Groups are drawn from the partial-design ANOVAs.

location (5.68 *vs.* 4.84), $F(1, 17) = 7.84$, $p = 0.012$, and slope (1.02 *vs.* 1.72), $F(1, 17) = 7.24$, $p = 0.015$.

To take the "missing" French /w/-/r/ subjects into account in comparison with the AE and Japanese groups, the overall percentages of "W" responses on the whole /w/-/r/ continuum were compared for the three groups of listeners. For this analysis, the Japanese results were pooled because the experienced and inexperienced subgroups of the Best & Strange (1992) study did not differ on the /w/-/r/ continuum. French, American, and Japanese participants, respectively, gave an average "W" response of 60.3, 44.2, and 51.2% on /w/-/r/. This simple approach to analyzing the data (from Yamada & Tohkura, 1992) is sufficient to show that, overall, French and Japanese listeners heard more /w/-like consonants in the /w/-/r/ continuum than Americans (French: $t(22) = 3.02$, $p = 0.0063$; Japanese: $t(16) = 2.47$, $p = 0.024$). This difference from the Americans was more pronounced for French listeners, who tended to hear more /w/-like consonants than Japanese (a non-significant trend, however).

The French listeners differed significantly from the Japanese (experienced or not) on the /w/-/j/ continuum, for boundary location (4.85 *vs.* 6.68 or 6.37), but not for slope. Boundary location for Japanese was shifted toward the /j/ endpoint, relative to both the French and American boundaries. Japanese listeners thus heard more /w/s than either other group[7] in /w/-/j/. Interestingly, for the /r/-/l/ continuum, French listeners did not differ from the experienced Japanese on either boundary location or slope; they differed only from the five inexperienced Japanese on both location (4.88 *vs.* 6.6), $F(1, 18) = 9.04$, $p = 0.0074$, and slope (1.53 *vs.* 0.46), $F(1, 18) = 25.38$, $p = 0.0001$. Finally, on the /w/-/r/ continuum, the French and Japanese listeners did not differ in either boundary locations or slopes.

2.2.2. *Discrimination*

The French discrimination data are summarized in Fig. 2, upper panels. Fig. 2 also reproduces the American and Japanese data from the Best & Strange (1992) study in the upper and lower panels, respectively. A comparison was conducted among the three language groups, based on the individual discrimination data from Best & Strange (1992). These data and the corresponding French data were entered in a Language $\times$ Series (3×3) ANOVA, in which the experienced and inexperienced Japanese data were pooled. (The performances of these two subgroups had differed mainly on the /r/-/l/ continuum.)

For the /w/-/j/ continuum, the overall performance of French listeners (88%) was significantly higher than that of either the Americans (75%) or the Japanese (77%), all *p*'s <0.002. For /r/-/l/, French participants performed slightly lower (73%) than Americans (78%), but significantly better than the Japanese (64%), $F(1, 22) = 5.27$, $p = 0.03$. Finally, for /w/-/r/, the French participants' performance (65%) was virtually identical to that of the Japanese (66%). It was significantly lower than that of Americans by about 10%, $F(1, 22) = 8.65$, $p = 0.0074$.

The discrimination data of the W-dominant and of the two-category French participants from the /w/-/r/ identification test were compared in an additional Group $\times$ Series (2×3) ANOVA. The overall performance of the two-category subgroup tended to be

[7] The Best& Strange (1992) interpretation, based on identification *and* discrimination data, was that the /w/-/j/ continuum encompassed a third category, /l/ for Americans, an atypical /w/ for Japanese.

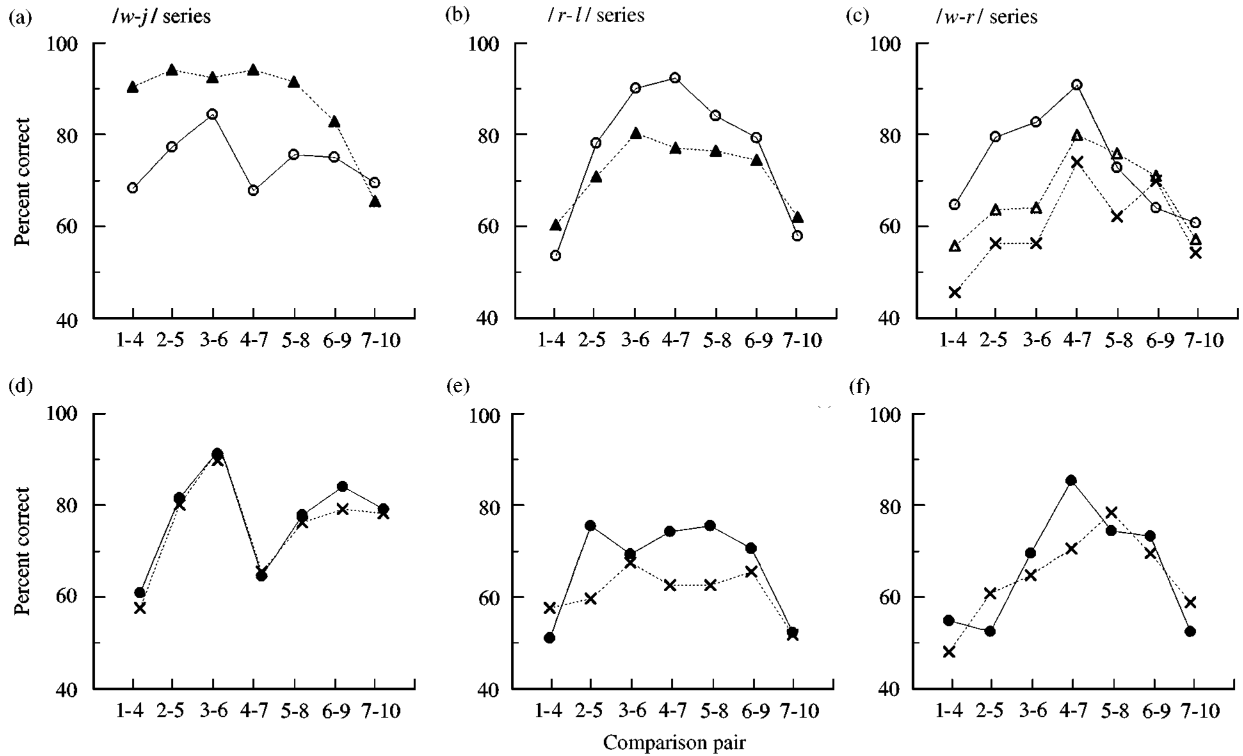

Figure 2. Discrimination functions for the /w-j/, /r-l/, and /w-r/ series. Upper panel Americans and French. The French data are pooled ((a) and (b)) or partitioned (c) into two-category and W-dominant participants for the /w-r/ series. Lower panel: experienced and inexperienced Japanese. The American and Japanese data are from the Best & Strange (1992) Experiment 1; the French data are from the present study, Experiment 1. (For panels (a)–(c): ——○—— Americans; ——▲—— French (pooled); ——△—— two-category French; ——×—— W-dominant French; for panels (d)–(f): ——●—— experienced Japanese; ——×—— inexperienced Japanese.)

better than that of the W-dominant subgroup for the /w/-/r/ series, $F(1, 13) = 3.31$, $p = 0.089$, but not for the other two series (both F's < 1). Considering the French and American groups only, there was a strong Language × Series interaction, $F(4, 44) = 9.58$, $p < 0.0001$. This interaction reflects the fact that Americans' performance was very homogeneous across the three series (75–78% correct overall), while the French performed at quite different levels according to series (/w/-/j/ ≫ /r/-/l/ > /w/-/r/). In more detail, analyzing separately the two-category and W-dominant subgroups, the latter difference (/r/-/l/ > /w/-/r/) was significant for the two-category subgroup, $F(1, 19) = 8.64$, $p = 0.016$, but not for the other French subgroup.

This overall comparison between language groups was complemented by a Series × Comparison Pair ANOVA run on the French data alone. The effect of Series was highly significant, $F(2, 28) = 60.14$, $p < 0.0001$, reflecting the fact that performance differed according to continuum. Indeed, French participants performed very well on the /w/-/j/ series (88% correct overall), whereas they performed rather poorly on the /w/-/r/ series (65%). Comparison Pair also had a highly significant effect, $F(6, 84) = 18.08$, $p < 0.0001$, reflecting that discrimination curves were far from flat. Even for the /w/-/j/ series, although the general shape of the discrimination function was high and flat until the sixth pair (values close to 90%), there was a sharp decrease in performance on the last pair. This mainly plateau-like shape of the /w/-/j/ discrimination function differed from the clearly two-peak shape observed on that continuum for both American and Japanese participants in the Best & Strange (1992) study. They presumably heard intermediate segments in the /w/-/j/ series (/l/-like consonants for Americans), and the two peaks were explained as reflecting the boundaries among the three categories contained in the /w/-/j/ series. In spite of the difference in the slope of discrimination function, the French participants' comments on the post-test questionnaire strongly suggested that they also heard an intermediate /l/-like consonant in the /w/-/j/ series, as Americans did. (Out of 14 participants' comments, six explicitly signaled they sometimes heard an /l/.)

For the /r/-/l/ series, the shape of the French discrimination function was plateau-like rather than clearly two-peaked. The plateau-like region began at the third pair of stimuli, for which the discrimination value was significantly higher than the two surrounding values at pairs 2 and 4, $F(1, 14) = 5.8$, $p = 0.029$. The plateau-like region ended at the sixth pair, which was significantly higher than the last (seventh) pair, $F(1, 15) = 14.38$, $p = 0.002$. Therefore, for the /r/-/l/ continuum, French and American listeners differed qualitatively rather than quantitatively. Whereas the discrimination function of American participants showed a single peak roughly corresponding to their categorical boundary between /r/ and /l/ (Best & Strange, 1992), the French discrimination function was plateau-like, similar to the plateau-like or double-peaked pattern found for Japanese listeners (Best & Strange, 1992; MacKain et al., 1981; Mochizuki, 1981; Yamada & Tohkura, 1992). In contrast to /w/-/j/ and /r/-/l/, discrimination curves of the French listeners, for the /w/-/r/ series, had a single peak at the fourth pair.

2.3. *Discussion*

Together, the results suggest that French listeners have some difficulty with perceiving the properties of AE /r/. This difficulty is not as marked as for inexperienced Japanese listeners' perception of the /r/-/l/ continuum. Nonetheless, compared to

American listeners, French listeners exhibited shallower identification functions for both continua involving /r/, and tended to report fewer "R"s overall, especially on the /w/-/r/ continuum. The difference was also apparent in discrimination performances. On /r/-/l/, French listeners, unlike Americans, but somewhat reminiscent of the experienced Japanese in Best & Strange (1992), tended to have a plateau-like discrimination function, suggesting that this continuum encompassed more than two French categories. In their post-test questionnaire comments on the /r/-/l/ tests, only eight participants attempted to describe what they heard. Three participants pointed out that the more /l/-like consonants were easier to label and were close to French /l/. Three participants reported hearing "intermediary" segments similar to /w/ or /gw/. These comments suggest that AE /r/, or ambiguous consonants between AE /r/ and /l/, may be perceived as /w/-like by French listeners. This suggestion is also supported by the French participants' identification performance on the /w/-/r/ continuum, on which they reported more "W"s than "R"s on average.

Overall, the performance of French listeners, in terms of both category boundary precision and mean level of discrimination, followed the pattern /w/-/j/ ≫ /r/-/l/ > /w/-/r/. In contrast, the previously reported pattern for Japanese listeners on the same continua was /w/-/j/ > /w/-/r/ ≫ /r/-/l/, whereas that of Americans was essentially equal across all three contrasts (Best & Strange, 1992). Moreover, the French listeners out-performed the Japanese on the /r/-/l/ continuum, but not on the /w/-/r/ continuum. These performance patterns for the French relative to the other two groups are highly consistent with the predictions based on a phonetic-articulatory account of non-native speech perception effects. They are, on the other hand, clearly discrepant from the predictions of the classic phonological account.

The possibility that French listeners hear /w/-like consonants in the /r/-/l/ continuum, together with the tendency to label the /r/ endpoint as "W" in the /w-r/ series, would support the view that French listeners assimilate AE /r/, or some intermediate stimuli in the /r/-/l/ continuum, as being somewhat similar to French /w/. This motivated our second experiment, in which a third choice was available in the identification test for the /r/-/l/ ("W") and /w/-/j/ ("L") continua.

3. Experiment 2

This experiment was designed mainly to explore the possibility that French listeners perceive /w/-like consonants in /r/-/l/. For comparison with the second experiment of the Best & Strange (1992) study, we also examined whether French participants hear /l/-like consonants in the /w/-/j/ continuum. Perception of /l/s in the middle of that series had been observed for Americans, apparently because the intermediate stimuli shared some similarity with AE /l/ (i.e., the endpoint stimulus of the /r/-/l/ series). Japanese listeners in that study also appeared to discriminate an intermediate category in the /w/-/j/ series, although their identification of that category was not assessed. Given that French /l/ is relatively similar to AE /l/, French listeners might as well label intermediate stimuli of the /w-j/ series as /l/. Experiment 2 thus consisted of two three-choice identification tests for the /r/-/l/ ("R", "W", and "L" choices) and the /w/-/j/ ("W", "L", and "Y" choices) continua. The new participants in Experiment 2 were also tested on the corresponding discrimination tasks.

3.1. *Method*

3.1.1. *Participants*

Fourteen French university students ($M = 25.6$ years, range = 20–25 years) participated in this study for payment. None of them had participated in Experiment 1. Eleven participants had lived most of their lives in the Ile de France region. The other three grew up in the central, southeastern, or southwestern regions of France; their perceptual data were not noticeably different from the others. All reported little spoken English experience.[8] One participant was eliminated for near chance-level performance on all three continua.

3.4.2. *Stimulus materials*

The same /r-l/ and /w-j/ series as in Experiment 1 and Best & Strange (1992) were used.

3.1.3. *Procedure*

The same procedure as in Experiment 1 was used with the exception that a third choice was included in each of the two identification tests. Participants were run in two different sessions (at 2 day intervals), one for each continuum. Session order was counterbalanced between participants. In each session, participants first completed a three-way forced choice identification test, then an AXB discrimination test; they were allowed a 15 min break between the two tests. Participants were tested individually under the same conditions as in Experiment 1, and were also asked to complete a posttest questionnaire about their perception of the stimuli after their second test session was finished.

The identification tests consisted of 20 blocks of 10 trials, each stimulus being presented 20 times. Presentation order was randomized. The intertrial and interblock intervals were 2.5 s and 4 s, respectively. An answer sheet was prepared, containing for each trial the trial number followed by three letters “R”, “W”, and “L” for the /r-l/ series, and “W”, “ L”, and “Y” for the /w-j/ series. For each trial, the participant had to circle one of the three letters to indicate the initial consonant they heard. The discrimination test was run by following the same procedure as in Experiment 1 in every detail.

3.2. *Results and discussion*

3.2.1. */w/-/j/ continuum*

The identification functions for the /w/-/j/ series averaged across participants for the French (present study) and the Americans (Best & Strange, 1992, Experiment 2) are shown in Fig. 3. They are quite similar. French listeners, like Americans, divided the continuum into three sharply distinct categories. They heard /l/ consistently in the intermediate stimuli in this series, with a peak percentage of “L” responses reaching about 95%, similar to that of Americans. (Americans, however, tended to hear more /l/s than the French overall (38 against 33%) as can be seen in Fig. 3.) Intercepts and slopes for the two /w/-/l/ and /l/-/j/ boundaries, as estimated with the same PROBIT analysis as

[8]As in Experiment 1, participants in Experiment 2 completed the self-rating scales on English proficiency. The range of the final participants’ oral–aural ratings fell between 2 and 8 (for a maximum 10), yielding a mean rating of 6.5.

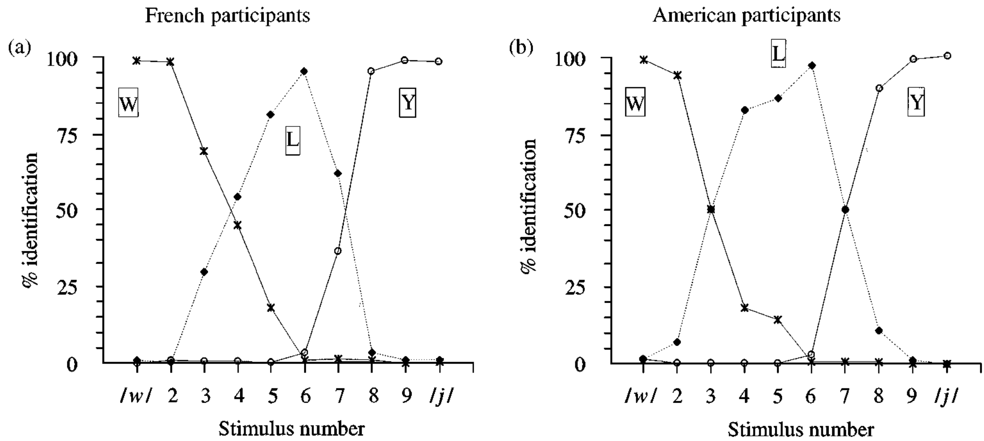

Figure 3. Identification functions for the /w/-/j/ series for (a) French (Experiment 2) and (b) American (Best & Strange (1992) Experiment 2) participants.

TABLE III. Three-choice identification test on the /w-j/ series for French (Experiment 2) and American (Best & Strange, 1992, Experiment 2) participants: boundary locations (/w-l/ and /l-j/ boundaries) and corresponding slope values (same conventions as in Tables I and II)

	/w-l/			/l-j/		
	N	*M*	*SD*	N	*M*	*SD*
Boundary location						
French	14	3.83	(1.08)	14	7.18	(0.36)
Americans	9	3.26	(0.84)	9	7.20	(0.59)
Slope						
French	14	2.01	(0.73)	14	2.44	(0.92)
Americans	9	2.53	(1.39)	9	3.17	(1.17

in Experiment 1 for the French data, are summarized in Table III for French and American participants. These two groups did not differ significantly for either intercept or slope, on both boundaries.[9] We may conclude that these two language groups performed similarly on the /w/-/j/ continuum, with rather steep identification functions at both boundaries, clearly hearing an /l/-like consonant in the continuum. The perception of an /l/ in the /w/-/j/ series is presumably based on the acoustic properties of the ambiguous stimuli (see Best & Strange (1992) for a detailed account).

The French discrimination data are shown in Fig. 4(a), against the American data from Best & Strange (1992), Experiment 2. We analyzed the /w-j/ series discrimination data for the French groups (Experiments 1 and 2), and the American group in the Best & Strange (1992) Experiment 2 in a Group × Comparison Pair (3 × 7) ANOVA. This showed that

[9]The PROBIT analyses run in the present study used a slightly different algorithm than in the Best & Strange (1992) study, and generally yielded very similar intercepts but somewhat smaller slope values (see Footnote 5). Thus, identical PROBIT analyses would presumably have produced even closer slope values for French and American participants.

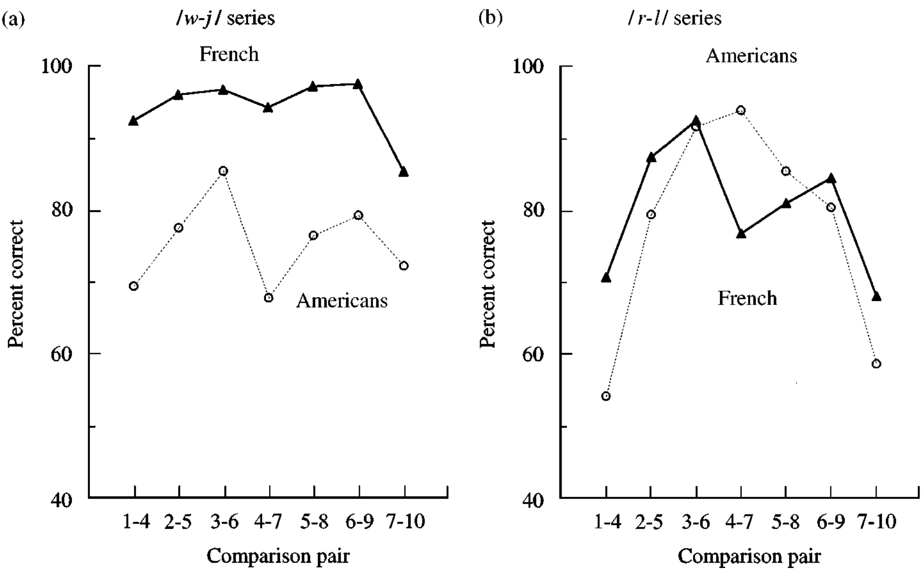

Figure 4. Discrimination functions on the (a) /w-j/ and (b) /r-l/ series, for French (Experiment 2), and American (from Best & Strange (1992), Experiments 2 and 1, respectively) participants.

the French performed better than Americans. The French participants tested in Experiment 2 performed nearly at ceiling (94% correct response), even better than those in Experiment 1, $F(1, 28) = 7.01$, $p = 0.013$, and much better than Americans, $F(1, 21) = 104.28$, $p < 0.0001$. Perhaps because of this ceiling effect, the new French discrimination data showed no clear evidence of a two-peak pattern. Although local maxima of correct discrimination were found at the third and sixth pairs, and a local minimum at the fourth pair, planned comparisons with the surrounding pairs revealed no significant difference. However, the shape of the discrimination function suggested that pairs 2 and 3 formed a wide peak, as did pairs 5 and 6. The difference between these pair sets and the surrounding pairs (pairs 1 and 4, and pairs 4 and 7) was nearly or clearly significant (pair 2–3: $F(1, 13) = 4.45$, $p = 0.053$; pair 5–6: $F(1, 13) = 13.88$, $p = 0.0026$.

Therefore, the French performance on the /w/-/j/ continuum, with a three-choice identification test, was similar to that of Americans with respect to identification. For discrimination, the French performance was, again, at ceiling level, and even better than in Experiment 1. This improvement may be due to either a between-group difference, or to the fact that participants in Experiment 2 had been run on a presumably more difficult three-choice identification test. This could have focused their attention on finer-grained phonetic differences and thereby enhanced their discrimination performance.

3.2.2. */r/-/l/ continuum*

For the /r-l/ series, the results were somewhat heterogeneous. Out of the 14 French participants, 10 divided the continuum into three clearly defined categories, with a /w/ category peaking at 63.3% (average peak value) for the intermediate stimulus number 5. Two participants had a clear /l/ category but responded "W" as often as "R" in the /r/

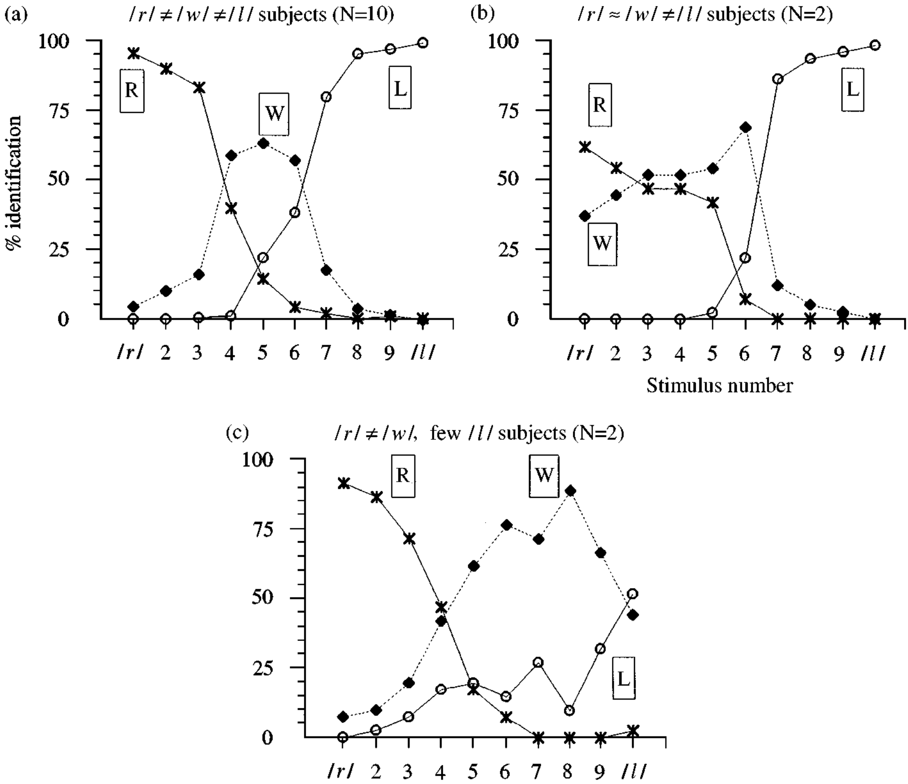

Figure 5. Identification functions for the /r/-/l/ series, Experiment 2, for the three-category participants (a), "/r/ $\approx$ /w/ $\neq$ /l/" (b), and "/r/ $\neq$ /w/, few /l/" (c) participants.

portion of the continuum (/r/ $\approx$ /w/ $\neq$ /l/ participants); two others participants had a clear /r/ category, but responded "W" for stimuli 5–9 and both "W" and "L" for stimulus 10 (/r/ $\neq$ /w/, few /l/ participants). These three patterns of responses are shown in Fig. 5.

The French discrimination data are shown in Fig. 4(b), against the American data from the Best & Strange (1992) Experiment 1. We analyzed the /r/-/l/ series discrimination data for the French groups (Experiments 1 and 2), and the American group in the Best & Strange (1992) Experiment 1, in a Group $\times$ Comparison Pair (3×7) ANOVA. Pairs 3 and 6 were clear local maxima, significantly higher than the two surrounding values (pair 3: $F(1, 13) = 22.68$, $p = 0.0004$; pair 6: $F(1, 13) = 8.51$, $p = 0.012$). A qualitative difference with American listeners thus appeared more clearly in Experiment 2: the /r/-/l/ discrimination function is single peak for Americans and double peak for French listeners. As for the /w/-/j/ series, the French participants in Experiment 2 performed better in their perception of the AE /r/-/l/ contrast than those in Experiment 1, $F(1, 28) = 8.03$, $p = 0.0082$. Yet, their overall performance did not differ from that of Americans in the Best & Strange (1992) Experiment 1, $F(1, 21) < 1$.

To summarize, these results confirm the notion that French listeners differ from Americans in their perception of the AE /r/-/l/ contrast. This difference is conceivably due to a tendency to interpret AE /r/ as a variant of /w/ (presumably, as a rather poor exemplar of a French /w/). This tendency is apparent from the /w/-/r/ and the /r/-/l/ data obtained in Experiments 1 and 2, respectively. As suggested by the French participants' comments, the third consonant category they hear along the /r/-/l/ series is similar to /w/.

Interestingly, we also found that two French participants tended to label AE /l/s as "W." This could be explained by the velar, "dark", quality of the English /l/ that is widely acknowledged (Giles & Moll, 1975; Hardcastle & Barry, 1989; Sproat & Fujimura, 1993; Browman & Goldstein, 1995), an articulatory feature that is not found in French /l/ (Simon, 1967; Delattre, 1969, 1971*a*; Chafcouloff, 1972, 1979), but is widely reported to occur with /w/ (Chafcouloff, 1979; Espy-Wilson, 1992). Note that the children's production literature has often documented the tendency of English-learning children to replace /l/ with /w/ (Snow, 1963; Olmsted, 1971). Perception data suggest that the tendency to neutralize the /w/-/l/ contrast is correlated with a fuzzier than usual perception of this contrast (Broen, Strange, Doyle & Heller, 1983). Thus, it is perhaps not too surprising that French listeners occasionally mislabel these two consonants.

4. General discussion

The results of this series of experiments show that French listeners perceive and discriminate American English /w j l r/ contrasts differently than both American and Japanese listeners. Below, we summarize the findings for the three continua. We go on to discuss in greater depth possible accounts of the results by current models of cross-language speech perception, and more importantly, in terms of articulatory-phonetic *vs.* abstract phonology considerations.

For the /w/-/j/ continuum, French identification data were very similar to previous American data (Best & Strange, 1992) on both two- and three-choice tests. This is in line with the prediction that /w/-/j/ should be as easy for French listeners to categorize and discriminate as it has been for Americans (Best & Strange, 1992), which is consistent with either the articulatory-phonetic or the abstract phonology viewpoints. What is surprising, however, is that the French listeners discriminated significantly and substantially *better* than the Americans. This unexpected cross-language difference was consistent across both experiments, and as we suggest later, may be explainable with reference to phonetic differences between the two languages.

For /r/-/l/, French participants were significantly less accurate than Americans on the identification test (shallower slopes), and tended to label the stimuli as "R" less often than the Americans. The discrimination functions of French participants were plateau-like or clearly two-peaked (Experiments 1 and 2, respectively), as opposed to the higher, single-peaked functions of the Americans. Moreover, overall discrimination performance was slightly below that of American listeners. The Language × Series interaction indicated that the /r/-/l/ contrast was substantially more difficult than /w/-/j/ for French listeners. This clearly suggests that the AE /r/-/l/ contrast is not processed by French listeners in the same way as /w/-/j/, especially in comparison with the Americans, as an abstract phonology account would predict.

The /w/-/r/ contrast was by far the most difficult for French listeners, both for identification and for discrimination, which fell significantly below the levels previously shown by Americans (Best & Strange, 1992). Although the majority of French participants divided the continuum fairly cleanly into two categories, they showed relatively low discrimination performance. A minority of French participants heard predominantly /w/-like consonants throughout the continuum (Fig. 1(c)), and tended toward even lower discrimination performance (Fig. 2(c)). The lower discrimination level for /w/-/r/ than for /r/-/l/ and the labeling difficulty for /w/-/r/ are consistent with an interpretation in terms of articulatory-phonetic properties rather than solely in terms of abstract phonological considerations.

Overall, the results suggest that French listeners, like Japanese listeners, have difficulty perceiving AE /r/. But the French listener's difficulty with AE /r/ did not manifest itself in the same way as it had for the Japanese (Best & Strange, 1992). French participants had much less difficulty than the inexperienced Japanese on AE /r/-/l/, yet a subset of the French ("W-dominant" participants) had greater difficulty than the Japanese in identifying AE /w-r/. Whereas the inexperienced Japanese had encountered rather dramatic labeling and discriminating difficulties with the AE /r/-/l/ continuum, they had performed quite well for the AE /w/-/r/ continuum.

One possible explanation of these patterns of perception is that the Japanese — at least the inexperienced Japanese — hear both AE /r/ and /l/ as almost equally poor exemplars of Japanese /r/[10] (see Takagi, 1995, for a detailed account), whereas our results suggest that French listeners tend to hear AE /r/ as rather /w/-like. Moreover, AE /w/ is an acceptable /w/ for both Japanese and French, whereas AE /l/ is an acceptable /l/ only for French. Hence, French listeners may benefit from a /l/ "anchor" in their perception of the AE /r/-/l/ continuum. Conversely, Japanese listeners may benefit more than the French from a /w/ anchor in perception of the AE /w/-/r/ continuum.

This account is based on the notion that AE /r/ can be heard by French listeners as a sort of /w/, which was clearly the case for the "W-dominant" participants in Experiment 1. Was it the case for the "two-category" participants in Experiment 2 as well? As we suggested earlier, French listeners might have perceived AE /r/ as a poor French /w/. Hence, the French labeling of the /w/-/r/ continuum could have been driven by "W" percepts. That is, they could have responded "W" to the stimuli that sounded reasonably acceptable as /w/, and then responded "R" to those stimuli that they heard as notably less acceptable /w/s. Converging support for this suggestion comes from the French discrimination pattern for the /r/-/l/ continuum, which was found in Experiment 2 to encompass a third intervening phonetic category that was often labeled "W" by French listeners. Note that from an acoustic point of view, the best match with French /w/ is probably not exactly AE /r/, but, rather, the intermediate items in the AE /r/-/l/ series (Indeed, the F3 trajectories for the intermediate stimuli are close to that for AE /w/, which is itself close to French /w/.)

In any case, perception of /w/-like properties in AE /r/ is not too surprising, in the light of reports on phonological development and cross-language differences in the production and perception of /r/s. Children's substitutions of one approximant for another, referred to as "gliding," is especially common in English for /r/-to-/w/ substitutions (Snow, 1963). Relatedly, /r/-misarticulating children tend to misperceive /r/ as /w/

[10]Empirical evidence actually suggests that Japanese listeners more readily assimilate AE /l/ than AE /r/ to Japanese /r/. For example, in word-final position, AE /r/ is often perceived by Japanese listeners as the vowel /a/ (which is corroborated by the kana transcriptions of English loan-words, e.g., "maker" transcribed *me-e-ka-a*), whereas /l/ in the same position may be perceived as Japanese /ru/ (also see transcriptions of English word-final /l/ with *ru*, as in "goal" transcribed *go-o-ru*; interestingly, *ga-a-ru* for "girl" combines *a* for /r/ and *ru* for /l/). This could be yet another illustration that cross-language patterns of perceptual assimilation are governed by articulatory-phonetic similarity rather than by abstract phonological function.

(Strange & Broen, 1981; Broen, Strange, Doyle, & Heller, 1983; Hoffman, Daniloff, Bengoa, & Schuckers, 1985; Ohde & Sharf, 1988). In normal children this tendency is weaker, although it has been reported for three-year olds (Slawinski & Fitzgerald, 1998). It is interesting to note that /r/-to-/w/ gliding is less common in languages in which /r/ is phonetically very different from /w/, particularly when /r/ is a trill or a flap rather than an English-like approximant (Locke, 1983, p. 67). Anecdotal evidence suggests that the gliding tendency is present for French /r/, where it can be observed in /r/ misarticulations, in certain foreign accents, and in some French-creole languages.

Whether or not the preceding account is the best explanation of the findings, the difficulties encountered by French listeners increase across the AE continua, showing the pattern /w/-/j/ ≫ /r/-/l/ > /w/-/r/. This is clearly consistent with predictions based on articulatory-phonetics rather than those based on abstract phonological considerations, as outlined in the Introduction, and compatible with the conclusions drawn from the earlier-reported Japanese pattern of /w/-/j/ > /w/-/r/ ≫ /r/-/l/ (Best & Strange, 1992). To refine our account based on articulatory-phonetic considerations, we must acknowledge that the cross-language differences between French and Japanese listeners may be partly due to mitigating influences that biased these listeners in different, language-specific ways. One such influence comes from the writing system of their native language which can provide a model for phonemic categorization (see Olson, 1996). The labels "R" and "L" might be easier to use for French than Japanese listeners because these graphemes occur in written French but not in the most common Japanese writing system, i.e., kana writing. Japanese lacks a symbol for /l/; thus when a word borrowed from English contains either /l/ or /r/, the corresponding syllable is transliterated in Japanese as a kana of the R-series.

We must acknowledge, before turning to a broader discussion of the implications of our findings, that the reported study is but a first step toward examining the contributions of language-specific articulatory-phonetic details, versus abstract phonological properties, to non-native speech perception. Additional research will be needed to extend these findings to additional phonetic contexts, to other types of contrasts, to other languages and listener groups, and to natural as well as synthetic speech. Nonetheless, it is likely that such stimulus and subject comparisons will produce variations in perception, which would only strengthen the conclusion we offer here: that detailed phonetic properties contribute substantially more than abstract phonological characterizations alone to non-native speech perception.

We turn now to the question of how well current models of cross-language speech perception might handle the present findings. We begin with the Perceptual Assimilation Model (PAM) (Best, McRoberts, & Sithole, 1988; Best, 1994, 1995). Following the account we offered above, both the /w/-/j/ and the /r/-/l/ contrasts would be considered by PAM as "two-category" (TC) assimilation patterns for French listeners. However, there is a clear difference between those two AE contrasts in how well the non-native categories match native French categories. Specifically, AE /r/ appears to be a relatively poor match to /w/ for most French listeners. If AE /r/ sounds like a less-than-ideal /w/ to the French, then the AE /w/-/r/ contrast would be, in PAM terms, a "category-goodness" (CG) assimilation type contrast, or perhaps a "single-category" (SC) contrast for "W-dominant" participants. Note that individual differences may be real (in the sense that they reflect different perceptual organizations), or they may reflect varying degrees of bias arising from the listeners' experience with English or from the native-language writing system (Olson, 1996). In its current version, PAM could account for the observation that AE /w/-/r/ is perceptually more difficult for French listeners than /r/-/l/ and /w/-/j/. However, further elaboration is clearly needed to account for quantitative differences within the same assimilation type, viz. the TC pattern. The /w/-/j/ contrast provides a telling illustration, because it should be a TC contrast for either Japanese or French listeners. The current version of PAM simply predicts that discrimination should be "excellent" in TC cases (Best et al., 1988; Best, 1992; Best & Strange, 1992). Yet, French listeners were much better in discriminating /w/-/j/ than Japanese or American listeners. They were also much better on /w/-/j/ than on /r/-/l/, for which they also presumably showed TC assimilation. The PAM model would need to be refined in order to account for such quantitative variations within a given assimilation type. For example, it could be that TC contrasts are easier to discriminate when the articulatory-phonetic properties of the non-native phones are a good rather than poor fit to the associated native categories. However, even that modification is insufficient to explain why the French discriminated /w/-/j/ better than the Americans (or the Japanese). In response, we suggest that the French listeners' better performance may be related to the more densely packed phonetic space for semivowels in French than in the other two languages, which could result in greater sensitivity to semivowel contrasts. Specifically, the other languages have two semivowels, /w/ and /j/, whereas French adds a third semivowel [ɥ] between them (a palato-labial glide, associated with the high front vowel /y/, as in *huit*/ɥit/, "eight," or *huile*/ɥil/, "oil").

By comparison with PAM, the Speech Learning Model (SLM) (Flege, 1986, 1991, 1995) is oriented toward single phones rather than contrasts. Non-native phones may be *identical*, *similar*, or *new*, relative to the native categories. The *similar* phones are considered to be the most difficult to perceive and produce because they become "equivalence-classified" to the corresponding L1 category. Based on this view, AE /r/ could be *similar* to French /w/, and would thus be intrinsically very difficult for French listeners to distinguish from the identically classified AE /w/. However, more detailed discussion of an SLM account for the French listeners' relative performance differences among the three continua would be highly speculative, because this model does not explicitly predict varying degrees of difficulty between extremely good *vs.* extremely poor levels of discrimination and categorization.

Because the Native Language Magnet model (NLM: Kuhl, 1991; Kuhl, Williams, Lacerda, Stevens & Lindblom, 1992; Iverson & Kuhl, 1995, 1996) is primarily concerned with the internal organization of individual phonetic categories, it applies most directly to the patterns of discrimination observed within native categories (i.e., to CG and SC assimilation types in PAM's formulation). NLM most directly addresses AE /w/-/r/, presumably perceived as a CG contrast by the majority of French participants and as a SC contrast by the remaining minority (the W-dominant listeners). If we assume that AE /w/ is a better exemplar (i.e, more prototypical) of French /w/ than is AE /r/, NLM would predict better discrimination by French listeners in the region of /r/ than of /w/ on the /w/-/r/ continuum. However, this pattern was not observed with the two-category French subgroup, and although the "W-dominant" French listeners tended to perform better at the /r/ end than at the /w/ end (56 *vs.* 46% correct), this trend was not significant ($F(1, 14) = 2.84$, $p = 0.17$).

On the other hand, NLM could account for why the French performed better than the Americans on the intermediate region of the /w/-/j/ continuum, where both groups heard /l/s. Indeed, these /l/s were necessarily "/w/-colored" (i.e., "dark" or velarized) and thus closer to AE than to French prototypes of /l/, thus increasing discriminability for the French listeners relative to the Americans.

None of these theoretical models seems to be sufficiently detailed in its predictions, or in the way these predictions may be supported by quantitative data, to explain all details of the present findings. But PAM seems the most capable of the three to provide a useful framework for beginning to describe differing assimilation types and the relative (if not absolute) levels of difficulty with which they are associated.

Regardless of the specific theoretical models discussed, an important central point can be drawn from the results of the present investigation: articulatory-phonetic considerations, and not only abstract phonological considerations and descriptions, must be taken into account to explain non-native speech perception performance. In abstract phonological descriptions, speech segments can be compared between languages only on the basis of the structural position they occupy in the phonological systems of the languages, according to their functional and combinatorial properties, or to the allophonic and morphophonemic alternations they are submitted to. We suggest that the comparative articulatory-phonetic details of two or more languages are more clearly associated with detailed variations in performance on different non-native contrasts than are abstract phonological descriptions alone. This does not radically exclude the role of the native language sound system on the perception of non-native contrasts from a structural, phonological standpoint. For instance, the English contrast /si/-/ʃi/ may be a difficult one for Japanese listeners probably because there are distributional gaps in the Japanese repertoire of syllables: in particular, /s/ normally does not combine with /i/. Here, a phonological account could be more appropriate than a phonetic account. So, the picture is not an either-or choice between phonological *vs.* phonetic accounts. Yet, we believe there is a need to place increased emphasis on the explanatory power of articulatory-phonetic considerations in the field of cross-language speech perception.

In order to account for the pattern of speech perception findings across languages, a *realistic* phonology should thus incorporate articulatory-phonetic descriptions of the segmental categories and contrasts in each language. This kind of phonology, grounded in the reality of speech production, is proposed in the Articulatory Phonology developed by Browman & Goldstein (1989, 1995; and Goldstein & Browman (1986; also see Archangeli & Pulleyblank, 1994; Keating, 1984, 1985*a,b*). From this perspective of cross-language speech perception we believe this kind of framework is better able to predict and explain the perceptual performance of native *vs.* non-native speaker-listeners than are more traditional models based solely on abstract phonology considerations. From this sort of realistic, articulatory phonologic perspective, cross-language speech perception investigations can be seen to provide a window on listeners' knowledge of speech organization in their native language (Best, 1995).

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