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The role of gestural overlap in perceptual place assimilation in Korean

Minjung Son, Alexei Kochetov and Marianne Pouplier*

Abstract

Opposing views have emerged in phonological and phonetic theory on whether perceptual place assimilation is exclusively attributable to gestural reduction or can be triggered by gestural overlap as well. Specifically, regressive place assimilation in Korean /pk/ clusters has been used as argument for the hypothesis that gestural reduction is uniquely responsible for perceptual place assimilation, yet the empirical evidence for this reduction hypothesis is ambiguous. The present study demonstrates on the basis of articulatory movement data that in these /pk/ clusters the lip gesture for /p/ is either fully present (with varying degrees of overlap) or completely absent. Our data suggest that assimilation in Korean /pk/ clusters is a result of articulatory (not perceptual) place assimilation. To investigate the role of overlap in perceptual place assimilation, the data obtained in the production experiment were used in a phoneme identification experiment with Korean and English listeners. Both subject groups showed that gestural overlap consistently leads to perceptual ambiguity within and between subjects. The results suggest that gestural overlap can be regarded as an important factor in the evolution of language-particular patterns of assimilation.

Introduction

The question of the origins of place assimilation has been a subject of increasing interest and controversy, particularly in the context of connected speech phenomena (e.g., Ohala 1990; Barry 1991; Browman and Goldstein 1990, 1992a,b; Byrd 1992, 1996; Hura, Lindblom, and Diehl 1992; Jun 1995; Chen 2003). These phenomena – gradient overlap, reduction, and blending of articulatory gestures – were hypothesized to obscure place of articulation information available in the acoustic signal and to cause listeners to perceive one of the consonants (C1) as having the same place of articulation as the following consonant (C2) in a C1C2 cluster. For example, in the phrase *perfect memory*, the final coronal, although being fully articulated, can perceptually come to be completely obscured by the following labial (Browman and Goldstein 1990; Tiede et al. 2001; Surprenant and Goldstein 1998). Such an assimilated percept will be further referred to as 'perceptual place assimilation.' Place assimilation can also be observed in production, among others through gestural reduction of C1 – with or without concomitant temporal extension of the C2 gesture (e.g. Barry 1991; Nolan 1992; Honorof 1999).

Browman and Goldstein (1992b: 228), among others, note that gestural reduction of C1 and temporal extension of C2 in a C1C2 cluster may be either gradient or categorical, the latter being "the kind of assimilation represented in feature geometry by the technique of linking and delinking." The distinction between (i) no reduction (accompanied by overlap), (ii) gradient reduction, and (iii) categorical reduction of gestures will be particularly important for the current study. The first category can be exemplified by English labials and dorsals as C1 in word-medial or across-word clusters (e.g. in *to[m]cat, a[k]tive,* or *to[p] class*): the lip aperture and tongue dorsum gestures do not appear to be reduced in space or time, despite being overlapped by the gestures of the following consonants. A classical example of the second category, gradient reduction, is provided by English word-final alveolars in across-word clusters (e.g. in *tha[$_t$] car* or *te[$_n$] pounds*): the tongue tip gesture shows gradient reduction in space and time, accompanied by overlap by and extension of the following gesture (Barry 1991, Browman and Goldstein 1992a, Nolan 1992). The third category, categorical reduction, can be exemplified by the English word-medial alveolar /n/ in certain morphological contexts (e.g. /ɪn-/ in *[ɪm]probable;* cf. *[ɪn]adequate*) or Castilian Spanish word-final alveolar /n/ (e.g. in *diga[m] paja* 'say straw', form. pl.; cf. *diga[n]*): the tongue tip gesture is categorically reduced and the lip aperture gesture is temporally extended (Honorof 1999).

Gradient assimilation processes (such as *tha[$_t$] car*) appear to have many properties of postlexical phonological rules (Kiparsky 1985, Mohanan 1995): they apply across word boundaries, do not refer to morphological or lexical categories, may not be structure-preserving, and are not easily accessible to native speaker intuitions. They also tend to be sensitive to speech rate and style (e.g., Barry 1991). Categorical assimilation processes (e.g. /ɪn-/ in *[ɪm]probable*), on the other hand, may have certain properties of lexical phonological rules: structure preservation, sensitivity to morphological and lexical information, and accessibility to native intuitions. Categorical assimilation processes tend to apply within a prosodic word, however, some of them may extend across word boundaries (such as Spanish nasal assimilation; Honorof 1999).

The interplay between different types of articulatory place assimilation and between articulatory and perceptual place assimilation appears to be a rather complex phenomenon. There are opposing views on whether perceptual place assimilation is exclusively attributable to gestural reduction (*gestural reduction hypothesis*; Jun 1995, 1996), or can be triggered by both gestural reduction and overlap (Browman and Goldstein 1992a; Surprenant and Goldstein 1998; Chen 2003).

Based on an examination of articulatory X-ray microbeam data on English word-final coronal assimilation, as well as a review of a number of articulatory and acoustic studies of this phenomenon, Browman and Goldstein (1992a: 173-174; cf. also 1990) took the position that "[i]n addition to reduction … the overlap between the gesture (reduced or not) and the following stop gesture may play a role in perceived assimilations." Specifically, perceptual assimilation was predicted to occur when the effect of gradient reduction or overlap exceeded "some perceptual threshold." The question of the relation between overlap and reduction was addressed systematically in Byrd (1992), who used synthetic nonsense utterances with /db/ and /bd/ clusters varying in the degree of overlap while having constant gestural magnitude. The results showed that greater overlap led to a higher rate of perceptual assimilation by English listeners, especially when the first consonant was the coronal /d/. These findings were later supported in a perceptual study with natural English utterances from an X-ray microbeam study in Surprenant and Goldstein (1998). The results showed that word-final alveolars were less reliably detected by listeners when they were partially or completely overlapped by following labials. Many of the alveolar tokens, however, were partially reduced, and thus the results did not distinguish between relative effects of overlap and reduction.

The question of recoverability of overlapped and reduced gestures was further addressed in Chen (2003), who used synthetic nonsense utterances with /db/ and /bd/ clusters, as in Byrd (1992). The gestures varied not only in terms of overlap, but also in terms of reduction of the first consonant gesture. A perceptual recovery model was used to detect the degree of overlap and reduction in the stimuli from the acoustic signal. The results confirmed the greater susceptibility of reduced or overlapped coronals to assimilation. More interestingly, Chen also showed that, at least in coronal-labial clusters, overlapped gestures could be 'perceived' as reduced. She concluded that an overlapped gesture produced by a speaker could be recovered by a listener as gradiently reduced and incorrectly imitated as such. Such 'mis-perceptions' and 'mis-imitations' could potentially get phonologized and thus result in a place assimilation process, either gradient or a categorical (cf. also Beddor, Krakow, and Goldstein 1986; Ohala 1990).

Challenging Browman and Goldstein's view Jun (1995, 1996) presented data on regressive place assimilation in the Korean labial-dorsal cluster /pk/ in support of the gestural reduction hypothesis. The process of labial assimilation, illustrated in (1) (Jun 1996: 404) is traditionally described as variable, applying in casual rather than formal style. Korean labials assimilate in place to dorsals only; alveolars, however, assimilate to both dorsals and labials (Kim-Renaud [1974] 1991).

(1)	/ip-ko/	[ikko]~[ipko]	'wear and'
	/ip-kwa/	[ikkwa]~[ipkwa]	'leaf and'
	/ip-ku-esə/	[ikkuesə]~[ipkuesə]	'entrance', LOC.
	/sip-ko/	[sikko]~[sipko]	'go', CON.

Investigating changes of oral pressure during the production of /pk/, Jun found that some tokens displayed gestural reduction (interpreted as "usually partial"; Jun 1996: 389) but no overlap, while other tokens showed gestural overlap without any reduction. Further the frequency of gestural reduction in his data was higher in fast, casual speech style compared to slow, formal style (cf. also Kim-Renaud 1991). Jun interpreted the results as evidence for reduction in Korean /pk/ clusters being a postlexical process, akin to the gradient, speech rate- and style-dependent reduction of English word-final alveolars (e.g. in *tha[$_t$] car* or *te[$_n$] pounds*). In a follow-up perceptual study with Korean and English listeners Jun found that reduced tokens of /pk/ were overwhelmingly perceived as assimilated [kk], while overlapped tokens did not undergo perceptual assimilation. His conclusion was, therefore, that gestural reduction, rather than overlap, was the main source of perceptual assimilation.

The goal of the present study is to further examine overlap and reduction in labial-dorsal clusters and to provide further support for the view that overlap can play a role in perceptual assimilation. First, on the basis of articulatory movement data we investigated gestural overlap and reduction in Korean /pk/ clusters, previously examined in Jun (1995, 1996) (Experiment 1). Second, in a perceptual study with Korean and English listeners we examined whether overlap can lead to perceptual assimilation of labials to dorsals (Experiment 2).

Experiment 1

Method

Tongue and lip movement data were collected using the Perkell-system electromagnetic midsagittal articulometer (EMMA) at Haskins Laboratories (Perkell et al. 1992). The apparatus allows the tracking of individual fleshpoints by means of small transducer coils attached to various points on the subject's vocal tract in the midsagittal plane. For all subjects, the transducers attached outside the vocal tract were nose ridge, upper lip and lower lip. The transducers inside the vocal tract were maxilla, lower incisors, and four tongue transducers: tongue tip, anterior tongue body, posterior tongue body and tongue dorsum. The voltages output by each transducer were low-pass filtered at 200 Hz through a hardware filter and subsequently sampled at 500 Hz by a computer. The data were smoothed by a low-pass filter of 15 Hz, and further corrected for head movement (on the basis of the reference receivers attached to the nose and upper teeth), rotated and translated to the occlusal plane. The occlusal plane was obtained by taping two transducer coils to a biteplate that subjects kept between their teeth for 3 seconds while data were acquired for these two transducer coils, as well as for the coils attached to the nose and maxilla. These occlusal data were used to compute a coordinate system in which the horizontal axis parallels the subject's bite plane. Standard calibration procedures were completed before each experiment. The resolution for all signals was 12 bit. The speech signal was sampled 20 kHz for all subjects. Acoustic data were collected with a Sennheiser shotgun microphone positioned ca. 30 cm from the subject's mouth. Stimuli were presented in Korean on a computer screen positioned about 1 m away from the subject.

Participants

Three native speakers of Seoul Korean participated in the experiment. All subjects were naïve as to the purposes of the experiment.

Experimental procedure and stimuli

Target words and word pairs were presented in the carrier phrase *neka* ____ *lanɨn malɨl tɨləpoassta* ('I have heard of___') for K1 and *neka* ____ *lako tɨləssə* ('I heard it as ___') for subjects K2 and K3.[1,2] Subjects were instructed to repeat each each sentence three times. Each sentence was presented three times, rendering nine repetitions of each target word or word pair.[3] The stimuli contained in random order /pk/, /kk/ and /pp/ word-medially as well as across word boundary. /kk/ and /pp/ served as control conditions. Two rate conditions were employed; subjects were instructed to repeat the sentences slowly or quickly. The rate conditions were blocked and elicited in a different order for each subject. The target words and word pairs used in the experiment are shown in (2). The symbols "-" and "#" represent a morpheme boundary and a word boundary, respectively, and broad phonetic transcription is employed.

(2)

a. control /pp/

transliteration	*phonetic transcription*	*gloss*
/ap^h-pal/	[appal]	'a front paw'
/ap^h # palapo-ko/	[appalapoko]	'to look forward and'

b. control /kk/

/ak-kam-cəŋ/	[akkamcəŋ]	'hostile feeling'
/ak # katatɨm-ko/	[akkatatɨmko]	'to renew spirit and' (in the context of a sports game)

c. /pk/ clusters

/ap^h-kalim/ [akkalim]~[apkalim] ‘a sense of what is good for oneself’

/ap^h # kalɨk^{h}i-ko/ [apkalɨk^{h}iko]~[akkalɨk^{h}iko] ‘to point forward and’

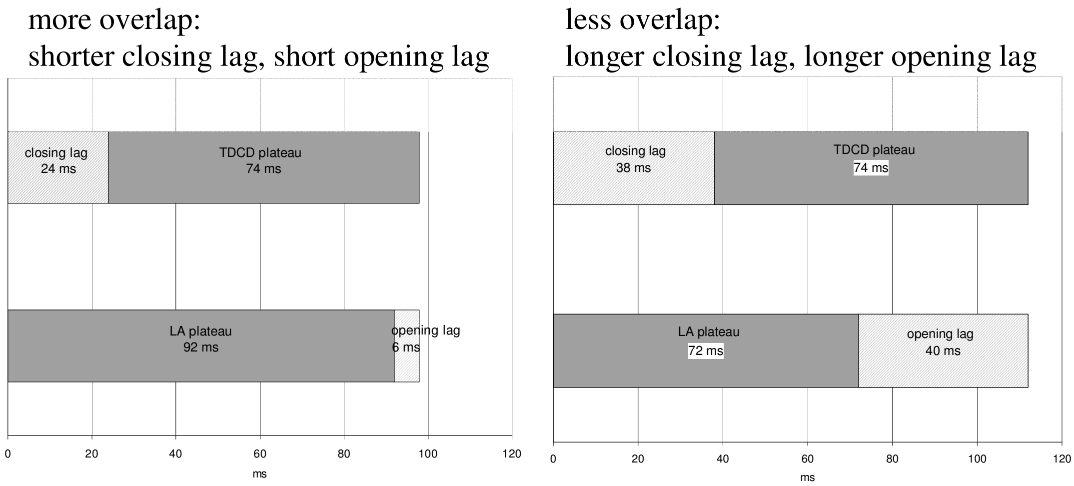
Measurements

For /p/ measurements, the time series for Lip Aperture (henceforth LA) was computed as the Euclidian distance between the upper lip and lower lip transducer coil. For the tongue dorsum gesture pertaining to /k/, constriction degree was calculated for the tongue dorsum transducer coil. Tongue dorsum constriction degree (henceforth TDCD) was calculated as the Euclidian distance of that transducer coil to all points on the palate. The minimal distance was taken as the constriction degree for that sample. An estimate of a subject’s palate was obtained by sampling at a .5 mm resolution all vertical position maxima of all four transducer coils attached to the tongue for each sample of the entire experiment. At equally spaced intervals with a 50 point density, this palate trace was then resampled on the basis of the convex hull formed by these vertical tongue transducer maxima.

Minimum constriction degree as well as the gestural landmarks ‘movement onset’, ‘target achievement’ and ‘release onset’ were identified using Matlab-based procedures developed at Haskins Laboratories. The gestural landmarks were defined by identifying the zero-crossings in the LA or TDCD velocity signals. In order to determine the degree of LA reduction in /pk/ tokens compared to LA during /pp/ and /kk/ controls, algorithmically determined vertical minima for the TDCD and LA time series were taken as an index of temporal location of the minimum constriction degree for /k/ and /p/, respectively. For the investigation of gestural overlap between the two adjacent stop gestures, several articulatory measurements were taken and related to each other. Onsets of motion were defined algorithmically as the points in time at which the velocity exceeded some specified threshold above zero velocity. Offsets were defined as the points where velocity fell below that same threshold. Thresholds were set as a percentage of the effective maximum speed that each transducer dimension exhibited over all utterances. The specific threshold value was different for each speaker but the same for all tokens of a given speaker. Percentages for TDCD ranged between speakers from 21 to 31% of the effective maximum velocity; for LA, between speakers 49 to 50% of the effective maximum velocity was used.[4]

Degree of overlap was assessed by measuring closing lag and opening lag (cf. Fig. 1). Closing lag was defined as the time (in ms.) between the end of the LA closing movement (achievement of target for /p/) and the end of TDCD closing movement (achievement of target for /k/). Opening lag was defined as the time between the beginning of LA opening movement (release of /p/-gesture) and the beginning of TDCD opening movement (release of /k/-gesture). For both measures, small numbers indicate a higher degree of overlap, while large numbers indicate a smaller degree of overlap. These are two of many possible measures of overlap; they were chosen because of their potential to be related to the amount of C1 information that is present in the VC1 part as well as the C2V part of the VC1C2V signal (cf. Surprenant and Goldstein 1998). Thus, for VC1C2V sequence, closing lag indicates how much C2 is present in the VC1 part, while opening lag indicates how much information of C1 is present in the C2V part.

Fig. 1. Typical examples for relatively more overlapped and relatively less overlapped production of /pk/ by one speaker (K3), slow rate.



To make our overlap results comparable to those in Jun (1995, 1996), we also calculated the overlap of LA and TDCD plateaus by subtracting the closing lag from the duration of the LA plateau for each given token. A positive value indicates that LA and TDCD plateaus were overlapped. This roughly corresponds to Jun's (1996: 382-383) category of "marked overlap" ("p^k" in his notation). A negative value indicates that LA and TDCD plateaus were not overlapped, corresponding to Jun's category of "slight or no overlap" ("p|k" in his notation). Note that despite their differences in the degree of overlap both tokens in Fig. 1 fall into the "marked overlap" category, since their LA and TDCD plateaus both overlap.

Results

Gestural reduction

Word-medially, all three speakers exhibited reduced LA during /p/ in /pk/ clusters. LA reduction was confined to word-medial position; it did not occur across word boundaries. Data for speaker K2 contained only a single instance of word-medial reduction; all other occurrences of /pk/ were unreduced. Across all subjects, the data revealed that lip aperture reduction in /pk/ was always categorical (i.e., /pk/ [kk]), albeit optional in its occurrence. For these tokens with a full reduction of the LA gesture, no LA minimum can be algorithmically identified. Where no LA minimum was present (reduced /pk/, control /kk/), LA was measured at the achievement of target for TDCD of each cluster. Accordingly, all /pk/ clusters were classified as either 'unreduced' or 'reduced.' LA means and standard deviations are displayed in Table 1.

Table 1. Means and *SD* LA for control /kk/, reduced /pk/ and unreduced /pk/ tokens by subject.

subject	mean LA and *SD* /kk/	mean LA and *SD* /pk/ reduced	mean LA and *SD* /pk/ unreduced
K1	36.59 (*SD* 1.3)	36.24 (*SD* 1.43)	20.23 (*SD* 1.89)
K2	16.47 (*SD* 1.75)	14.40 (*SD* n/a)	0.07 (*SD* 0.93)
K3	15.24 (*SD* 1.49)	14.74 (*SD* 1.4)	0.37 (*SD* 0.78)

The numerical results confirmed that for some tokens, the LA is fully reduced. No token exhibited a partial reduction of the LA gesture, which would be reflected in high standard deviations from the mean. A repeated measures ANOVA with the main factor LA reached significance ($F(2, 4) = 552.79$, $p < .0001$). A pairwise comparison of the means using Bonferroni's adjustment for multiple comparisons confirmed that the LA values for reduced /pk/ and control /kk/ were not significantly different from each other, while both groups were significantly different from unreduced /pk/. This result demonstrates that in our data, LA reduction in word-medial /pk/ clusters in Korean is of categorical magnitude, that is, the LA gesture is altogether absent.

For subject K1, all word-medial /pk/ tokens at the fast rate were of reduced magnitude; for subject K3, all word-medial token but one were reduced at the fast rate.

For K2, however, only a single token was reduced at the fast rate and none at the slow rate. In order to test statistically whether the occurrence of LA reduction was rate dependent, a Wilcoxon signed-rank test was conducted that compared the percentage of reduced /pk/ tokens for the two speech rates elicited (cf. Table 2).

Table 2. Percent /pk/ tokens with reduced LA per speaking rate.

Subject	*% /pk/ tokens with reduced LA*	
	Fast rate	*Slow rate*
K1	100%	87%
K2	11%	0%
K3	89%	44%

The test was not significant with $Z = -1.604$ ($p = .109$), indicating that the occurrence of LA reduction did not differ significantly with rate. While for K3, there were twice as many reduced tokens in the fast rate compared to the slow rate, the rate difference for the other two speakers was on an order of 11-13%.

The lack of difference between reduced /pk/ clusters and control /kk/ clusters in LA suggests that the assimilation process is categorical. Previous studies of English alveolar assimilation in hetero-organic clusters, however, have shown that even in cases when the tongue tip was maximally reduced ('a zero-alveolar') the assimilated cluster was still perceptually and presumably articulatorily different from the control homorganic clusters (Nolan 1992). It is thus possible that reduced /pk/ clusters are different from /kk/ in some other gestural variable, for example, the duration of the TDCD plateau could be shorter for /pk/ than for /kk/. Our measurements of this variable, however, revealed no significant differences between the reduced /pk/ and the control /kk/ within words (F(1,

107) = 1.466, *p* = .229). This further supports the categorical status of the labial assimilation.

<u>Overlap</u>

The results for the overlap measurements of closing and opening lag in unreduced /pk/ clusters are shown in Table 3. Recall that closing lag indicates the time interval between the end of the LA closing movement and the end of TDCD closing movement; opening lag indicates the time interval between the beginning of LA opening movement and the beginning of TDCD opening movement. For both measures smaller lag values indicate greater overlap of the lip aperture and tongue dorsum gestures. A repeated measures ANOVA showed that the closing lag was smaller in fast than in slow tokens ($F(1, 90) = 14.006$, $p < .001$). The opening lag differences across the rates were not significant, however, there was a significant subject * rate interaction ($F(2, 90) = 3.562$, $p < .05$), indicating a rate effect for one of the subjects (K1). Across subjects, as a combining effect of closing and opening lag differences, the gestures in fast tokens were overlapped to a greater extent than in slow tokens (on average by 19 ms.).

Table 3. Means and *SD* for closing and opening lag in ms. for overlapped /pk/ tokens by subject and rate.

subject	*closing lag (ms.)*		*opening lag (ms.)*	
	slow	fast	slow	fast
K1	56.80 (*SD* 15.43)	33.43 (*SD* 28.58)	39.36 (*SD* 13.20)	26.00 (*SD* 13.06)
K2	70.89 (*SD* 13.72)	54.47 (*SD* 17.63)	37.33 (*SD* 11.23)	34.00 (*SD* 11.62)
K3	31.43 (*SD* 10.03)	25.20 (*SD* 9.62)	12.43 (*SD* 16.04)	16.80 (*SD* 11.04)

The results for the overlap of LA and TDCD plateaus in unreduced /pk/ clusters are shown in Table 4. Here greater values indicate more overlap of the plateaus of the lip aperture and tongue dorsum gestures. Note that the mean values of plateau overlap for all three subjects and for both rates are positive, indicating that the TDCD target was almost always achieved prior to the LA release (cf. Fig. 1). In fact, there were only three tokens showing negative overlap values (mean: -4 ms (*SD* 3.46); K1) and one token with a zero overlap (K2). This suggests that, overall, the production of unreduced /pk/ clusters in the current study was characterized by "marked overlap" rather than "slight or no overlap" (cf. Jun 1996: 382-383).

Table 4. Means and *SD* for plateau overlap in ms. in overlapped /pk/ tokens by subject and rate.

subject	*plateau overlap (ms.)*	
	slow	fast
K1	21.76 (*SD* 15.52)	29.71 (*SD* 25.04)
K2	28.11 (*SD* 18.12)	26.00 (*SD* 15.36)
K3	50.29 (*SD* 13.65)	45.20 (*SD* 14.21)

Discussion

The results of the articulatory measurements reveal that Korean /pk/ clusters – at least in the forms elicited in the experiment – show, pooled across subjects, frequent labial reduction (18% of all tokens; 36% of word-medial tokens), albeit there being great inter-subject variability. The frequency of reduction across subjects is slightly lower than Jun's (1996) who reports 47% reduced word-medial tokens. Parallel to Jun, we find varying degrees of overlap in unreduced clusters. Our results show very few tokens with "slight or no overlap" (3% of all /pk/ tokens; cf. 16% in Jun (1996)). Labial reduction is sensitive to word/morphological boundaries: it is observed in word-medial clusters, but not in word-boundary clusters (contra Jun 1995). Reduction is optional in its occurrence, failing to apply in about two thirds of all word-medial tokens. It also occurs somewhat more frequently at higher speech rate. When it occurs, labial reduction in /pk/ is always complete (rendering [kk]), thus exhibiting properties of categorical articulatory place assimilation.

As to the magnitude of labial reduction, our current findings are largely at odds with Jun's (1996: 389) interpretation of this results; he concludes that “Korean labial reduction is usually partial (i.e. the gesture is weak).” Specifically, Jun’s air pressure data indicated that about half of word-medial /pk/ tokens were reduced. Note that he defines “reduction” as tokens where “the labial closure … was not made completely” (385), thus implying partial reduction. While also considering the possibility of complete reduction in some tokens, he assumes that: “at least some, if not all, <p>k tokens result from partial reduction of the labial” (389). However, with the instrumentation he employed lip aperture cannot be measured directly (as Jun acknowledges himself: 389, 401), making it hardly possible to determine both the degree of LA reduction and the difference between reduced tokens and the controls (kk). This opens the possibility that all of Jun’s “reduced” tokens could be in fact fully reduced, articulatorily assimilated (/pk/ [kk]) tokens, similar to those found in the current study.

Further, Jun (1996: 388-389) notes that some small pressure changes in some “marked overlap” tokens can be interpreted as being indicative of partial reduction, where the labial closure is “barely made.” However, all tokens exhibiting such small pressure changes contained the sequence velar stop + labial-velar glide, as in /ipkwa/. That is, small changes in oral pressure observed during these tokens cannot be uniquely attributed to a gradiently reduced /p/. Rather, these changes may in fact be due to the overlap of the tongue dorsum and lip gestures of the /kw/ sequence, while the LA gesture of /p/ may in fact be fully reduced. Our kinematic data allow for a direct measurement of LA and indeed reveal that labial reduction, if present, is categorical.

The comparison of word-medial and word-boundary /pk/ clusters in Jun (1995: 112) did not reveal significant differences between the two speaking style conditions: "in Korean, labials in the consonant cluster <u>pk</u> reduce as often across word boundaries as within words." This is contrary to the current results that show no labial reduction across word boundaries. The difference can be possibly attributed to different experimental conditions or a small number of speakers in the current experiment, yet the most plausible explanation for the discrepant results seems to be prosodic grouping. The two different groups of subjects (although both studies employed Seoul Korean speakers) may have grouped the stimulus phrases differently (note that there was a pronounced difference in carrier phrase between the two studies). The lack of gestural reduction in /pk/ clusters across word boundary in the current study may be due to the presence of an accentual phrase (henceforth AP) boundary between /p/ and /k/ in /pk/ clusters (Jun S., 1993, 1998; cf. Kuzla and Cho 2004).

To further investigate this possibility, we examined whether an AP boundary was present in our data between /ap^h/ and the first syllable of the adjacent morpheme /kalim/ (/pk/ word-medially with morpheme boundary) and that of the adjacent word /kalɨk^{h}ko/ (/pk/ in word-boundary condition).[5] We conducted a transcription analysis of the tonal realization of the target syllables relative to the adjacent tones, the presence of tensification of /k/, and the duration the vowel of /ap^h/ to see if there was enough time to realize a rising tone. A cluster was judged to be within a single AP when the first syllable /ap^h/ was realized with a low tone followed by a /ka/ syllable with both a high tone and tensification of /k/. The presence of an AP boundary was inferred from a rising tone on the first syllable /ap^h/, e.g., {L(HL)H} where the tones in parentheses indicate undershoot (cf. Jun, S. 1993), followed by a low tone on the second syllable /ka/, together with the absence of tensification. Perceptual judgments were made by one of the authors (MS), a native speaker of Korean, and were independently confirmed by another phonetician, also a native speaker of Korean.

With respect to the word-medial condition – the environment in which we observed LA reduction – the results showed that for all three speakers, all /pk/ clusters were consistently produced in one AP. As to the word-boundary condition, in which no reduction occurred in the current study, for K1, 100% of /pk/ clusters were produced in one AP (fast rate: 7 out of 7; slow rate: 22 out of 22 tokens). For K2, 17% of /pk/ clusters were produced in one AP (fast rate: 1 out of 9 tokens; slow: 3 out of 9 tokens) while 83% had an intervening AP boundary. For K3, 56 % of /pk/ clusters were produced in one AP (fast rate: 9 out of 9; slow rate: 1 out of 9 tokens) while the remaining tokens were produced in two APs.

To confirm the perceptual analysis, we further examined relative pitch contour. F_0 measurements were taken at the endpoint of the vowel in /ap^h/ and at the beginning of the vowel in /ka/; F_0 at the beginning of /ka/ was then subtracted from F_0 at the endpoint of /ap^h/. A negative number indicated that the /pk/ cluster was uttered in one AP while a positive number indicated the presence of an AP boundary. Some tokens had to be excluded from this analysis due to devoicing of /ka/. The results fully converged with the tonal transcriptions: all word-medial /pk/ clusters (with or without reduced LA) were produced within a single AP, while in the word-boundary condition, in which no LA reduction occurred, some tokens were produced within a single AP, while others were produced with an AP boundary between the /pk/ cluster. Although there was considerable between-subject variability in prosodic phrasing, we thus did not find that the lack of LA reduction in the word-boundary condition was contingent on the presence of an AP boundary. Likewise, word-medially the /pk/ cluster was always realized within a single AP, independent of whether LA reduction occurred. Since Jun (1995, 1996) did not investigate prosodic grouping for his data, it is not possible to compare the two studies in this respect.

It is worth noting that the lack of labial reduction was also observed in nonsense VCCV words. Son (2004) found neither partial nor complete reduction of the lip aperture gesture in her analysis of multiple productions of the nonsense word /epke/ produced by the same three speakers. This suggests that the process is not only sensitive to prosodic word boundaries, but is also sensitive to the lexical/morphological status of words, and thus not fully productive (contra Jun 1996: 401). Further research, involving a wider range of lexical and nonsense items and a systematic testing of the influence of prosodic grouping is needed to verify these findings.

A reviewer expressed the concern that the lack of reduction for some speakers in our data may be attributable to the laboratory situation which may not be conducive to investigate ‘casual speaking style’; that is, subjects may be hyperarticulating (note though that our findings are parallel to Jun’s data, where likewise some subjects did not exhibit reduction). However, as the reviewer also pointed out, the fact that a sizable number of reduced word-medial tokens was found in our study (comparable to Jun’s study) weakens the concern that the lack of gradience in reduction observed in our study may be an artifact of the experimental setup. Additional evidence against the hyperarticulation view comes from the finding that almost all unreduced /pk/ showed marked overlap, and that the degree of overlap (based on closing and opening lag) was greater under the fast speech condition.

In Jun's (1996) data, reduction was observed more frequently in casual rather than formal style (63% vs. 31%). Similar tendency was observed in our data, where reduction was somewhat more common under the fast rather than normal speech rate (67% vs. 44%). Jun found relatively high inter-speaker variation in labial reduction: for example, one of four speakers in Jun (1995: 112) showed no reduction whatsoever, four out of fourteen speakers in Jun (1996: 387) showed no reduction in formal style tokens, while four other speakers showed reduction in all formal style tokens. Similar variability was found in the current results: recall that one of our subjects (K2) showed no reduction in the slow rate condition.

Experiment 2

Stimuli

Productions of word-medial /pk/, /kk/ and /pp/ were selected from the EMMA data obtained for speaker K3. The data from this subject were chosen because it was the only subject that had both reduced and unreduced tokens at both rates. The VCCV portions of the words (i.e., [apka], [akka], [appa]) were extracted and amplitude equalized using Praat (Boersma and Weenink). Portions of real words, rather than complete words, were used in order to reduce any top down lexical effects for Korean listeners. Two tokens from each rate condition (fast, slow) were chosen from the /pp/, /kk/ control conditions and the reduced /pk/ productions. For unreduced /pk/, five tokens with different opening and closing lag values (i.e., different degrees of overlap) were chosen, with one token from the fast rate (the only unreduced token produced by this subject at the fast rate) and four tokens from the slow rate (cf. Table 5).

Table 5. Closing and opening lag in ms. for overlapped /pk/ tokens used in perception experiment.

token	*rate*	*closing lag (ms.)*	*opening lag (ms.)*
token 1	fast	18	30
token 2	slow	24	6
token 3	slow	26	50
token 4	slow	30	16
token 5	slow	38	40

Subjects

11 native speakers of Korean and 15 native speakers of Canadian English participated in the experiment. Results from two of the Canadian speakers were discarded since their responses were consistently false alarms independent of the tokens or monitoring conditions, which suggests that they misunderstood the instructions. Korean subjects were Yale University students; Canadian English subjects were Simon Fraser University undergraduate students. All subjects were naïve as to the purpose of the experiment.

Experimental setup and procedure

In a *go-no-go* task, participants were instructed to listen to short sound samples cut out from words (i.e., [apka], [akka], and [appa]) presented in random order and decide whether the consonant after the first vowel begins with a particular consonant sound. Using the software PsyScope (Cohen et al. 1993), each stimulus was presented 12 times overall (six times each in two different conditions), randomized differently each time. Subjects sat in a sound attenuated booth in front of a computer screen and keyboard. Stimuli were presented over headphones. Two different monitoring conditions were employed; in one condition subjects were asked to decide whether the first consonant they heard was a /p/-sound, in another condition subjects should monitor for a /k/-sound. If they heard the given sound, they were instructed to press the response key ({p} or {k} on the keyboard) as quickly as possible, otherwise, they were instructed to wait for the next trial. The conditions were blocked in cycles of three, that is, the program cycled three times through the entire stimulus list (51 tokens overall) in three different randomizations while subjects monitored for /p/. In the subsequent three cycles, subjects were asked to monitor for /k/, then again for /p/ and once more for /k/. Between these blocks of three cycles, subjects were given the option to take breaks, which they ended by pressing the space bar. During a given block, a letter representing the sound subjects should be monitoring for was displayed on the screen (in the font appropriate for the respective subject group). The time between the onset of two successive stimuli was 2000 ms., partitioned into a 1500 ms. response window and 500 ms. inter-trial time. During the window of 1500 ms. subjects heard the audio stimulus, and the response was recorded (the response window started with the onset of the audio stimulus). Independent of whether a response was recorded, the next trial came up after 2000 ms. A number of practice trials, containing a subset of the experimental stimuli from each condition, preceded the actual experiment. All practice trials appeared under both monitoring conditions in the practice session.

Results

Instead of analyzing percent of correct identifications directly, the data were transformed using d' as sensitivity measure (Macmillan and Creelman 1991). This measure takes into account subjects' inherent response bias by adjusting the number of hits (correct identification responses) for the number of false alarms (incorrect positive responses). This data evaluation method can thus also take into account any response bias that might be introduced through the monitoring condition (the letter on the screen in any given cycle). d' is computed by converting hit and false alarm proportions to z-scores and subtracting false alarms from hits; the formula is given in (1):

(1) $d' = z(H)-z(F)$

where H is the proportion of hits relative to the number of trials during which a signal is present and F is the proportion of false alarms relative to the number of trials during which no signal is present. Since perfect accuracy (only hits, no false alarms) has an infinite d' value, proportions of 1 and 0 need to be adjusted to a smaller value. Where $H = 0.99$ and $F = 0.01$, $d' = 4.65$, which is considered as effective ceiling (Macmillan and Creelman 1991). Proportions of 1 and 0 were thus adjusted to 0.99 and 0.01 respectively.

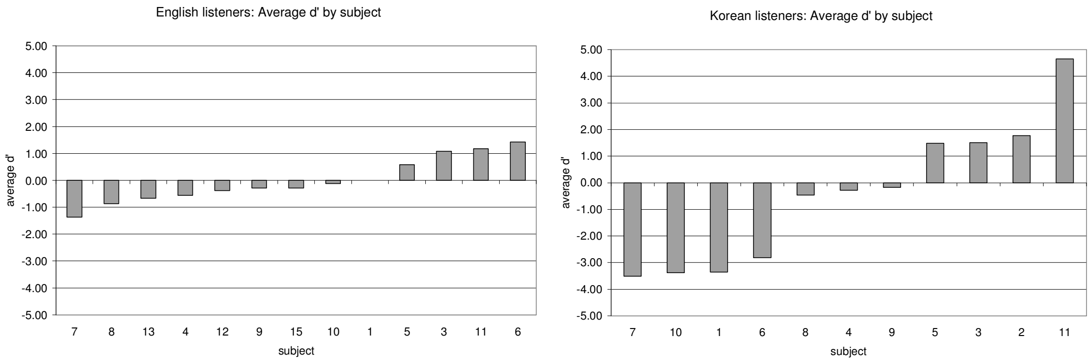
Reduced /pk/

For the Korean listeners, across subjects, reduced /pk/ was consistently identified as [kk]. The average d' value for /kk/ was 1.41 (*SD* 1.31), for /pp/ 1.84 (*SD* 1.14) and for reduced /pk/ -2.64 (*SD* .075). The same picture emerged for English listeners. The average d’ value for /kk/ was 1.71 (*SD* 1.22), for /pp/ 2.57 (*SD* 1.00) and for reduced /pk/ -2.4 (*SD* .97). The negative d’ value for reduced /pk/ tokens means that subjects systematically responded during the /k/ monitoring condition, but not during the /p/ monitoring condition to the reduced /pk/ stimuli. As expected for categorically reduced lip gestures, with the possibility of top-down interference from the lexicon removed, no LA gesture was heard.

<u>Overlapped /pk/</u>

d’ values for overlapped /pk/ tokens showed a rather surprising result. For both Korean as well as English listeners, average d’ values were around zero, indicating that listeners were not able to discriminate at all whether the first consonant was /p/ or /k/ (Korean listeners: d’ = -0.42, *SD* 2.38; English listeners: d’ = 0.26; *SD* 1.38). Looking at subjects’ responses individually, however, it becomes evident that this value arose for two reasons. First of all, for both listener groups, some subjects responded to the same token in both monitoring conditions. That is, for a given /pk/ token, some subjects hit the response key during the /p/-monitoring condition, indicating that they thought C1 was a labial, and also hit the response key during the /k/ monitoring condition, indicating that they thought C1 was a dorsal, rendering a d’ value of or around 0. Fig. 2 gives the average d’ responses by subject for English and Korean listeners separately (cf. Appendix for percent hit and false alarm responses by subject).

Fig. 2. Average d’ by subject for English and Korean listeners.



The graphs show why the across-subject-average d’ value was very similar for Korean and English listeners, although some Korean listeners showed much stronger d’ values. For English listeners, all subjects perceived the stimuli as ambiguous and consistently responded with both /p/ and /k/. Only for four subjects did the d’ values go below -1 or above 1 (S6 and S7, for S3 and S11 barely so), all other subjects identified a given token as /p/ and as /k/ with about equal frequency. Similar facts held for three out of the 11 Korean listeners; their d’ values hovered around zero (S4, S8, S9). For Korean subjects S2, S3, S5 there was a trend to perceive the overlapped /pk/ tokens as unassimilated appeared, although they still responded on a high number of trials during the /k/ monitoring condition as well, as manifest in a d’ value between 1 and 2. More interestingly, several Korean subjects did not perceive the stimuli as ambiguous, but instead as either unassimilated (S11) or fully assimilated (S1, S6, S7, S10). Subject 11 very clearly perceived the overlapped /pk/ tokens as unassimilated, indicated by a perfect identification score. The four remaining subjects (S1, S6, S7, S10), however, clearly perceived the tokens as assimilated – they responded during the /k/ monitoring condition, but not the /p/ monitoring condition, leading to a large negative d’ value. This between-subject variability also contributed to an overall near zero d’ average.[6]

It was further examined whether the perceptual results correlated with the articulatory overlap measures of closing and opening lag. For both closing and opening lag a positive correlation was predicted: The shorter the lag, the lower the d' value (i.e., the more perceptual place assimilation) was expected, since a short closing lag means that C2 potentially obscures the VC1 transition to a greater degree, and a short opening lag means that C1 obscures the C2V transition. None of the employed overlap measures yielded significance or a correlation coefficient of meaningful magnitude (Spearman's rho for ranked data). The ranges of overlap values and the relatively small number of tokens employed might not have been sufficient to uncover any potentially present stable pattern, especially in light of the extremely high within and between subject variability.

Discussion

The results of the perception experiment demonstrated that categorically reduced /pk/ tokens in Korean were heard as [kk]; the lip gesture was not perceptually interpolated. This held true for both of our listener groups. This replicates Jun's results in that reduced /pk/ tokens are perceived as [kk]. However, the results of Experiment 1 showed that this assimilation is entirely articulatory in nature; perception corresponds to the articulatory events in that no LA gesture is heard where no LA gesture is articulatorily present. Our data suggest that any potential unique contribution of reduction to perceptual place assimilation cannot be assessed on the basis of Korean word-medial /pk/ assimilation.

Jun (1995, 1996) takes the strong stance that overlap plays no role in perceptual place assimilation. The current results demonstrate that most subjects indeed detected place information for the labial as well as the dorsal stop in the acoustic signal. However, for English listeners in particular but also for about half of the Korean listeners, the overlap created perceptual ambiguity. This can be interpreted as a manifestation of gradience in perceptual place information in the sense that to the same token, subjects sometimes responded with /p/ and sometimes with /k/. That is, they heard the same /pk/ stimulus as [pk], [kk] or maybe also as [kp]. It appears that when no top-down information is available, gestural overlap leads to an ambiguous percept. Note that the use of VCCV sequences cut out from words as stimuli for the perception experiment could have contributed to the differences between the current results and those of Jun (1996), whose study employed real word stimuli and thus did not control for top-down effects. For the Korean subject group, only about half of the subjects perceived the signal as ambiguous. The other half perceived it as either assimilated or as unassimilated, with subjects being relatively or very consistent within themselves. This can be interpreted as between-subject gradience in perceptual place assimilation caused by overlap.

Overall, the current results demonstrate that overlap can lead to perceptual ambiguity within and between subjects. As such, overlap may contribute to perceptual place assimilation. For some Korean listeners, overlap very clearly resulted in perceptual place assimilation, while for others it had no effect on the perception of C1. A language specific pattern emerged in that for all English listeners, the tokens resulted in within-subject ambiguity, yet Korean listeners exhibited both within and between subject ambiguity. While findings of previous studies were limited to the role of overlap in coronal-noncoronal clusters, the current results show that substantial overlap may cause perceptual assimilation of labials, which are relatively perceptually robust (Byrd 1992, Chen 2003).

General discussion and conclusion

One of the main findings of Jun (1995, 1996) was that reduced /pk/ tokens led to an assimilated percept, [kk], while overlapped /pk/ tokens were largely perceived as unassimilated, [pk]. Assuming that labial reduction in Korean is mainly partial (Jun 1996: 389), Jun interprets this to mean that partial reduction alone can cause perceptual place assimilation. He concludes that place assimilation in the production of the Korean /pk/ cluster can uniquely be attributed to labial reduction and rejects the possibility that gestural overlap may play a role in perceptual place assimilation. The results of the current study, although limited in scope, present some evidence to the contrary. First, our results clearly show that, for the three speakers employed, labial reduction is categorical (/pk/   [kk]). This suggests that also Jun's subjects perceived reduced /pk/ tokens as [kk] simply because they were presented with [kk] – the labial gesture was probably articulatorily not present. To the extent that this is subject to confirmation by further research, gestural reduction in Korean /pk/ (at least synchronically) has no bearing on perceptual place assimilation. Second, the results of our study show that unreduced /pk/ clusters exhibit substantial gestural overlap. Importantly, this overlap can lead to perceptual ambiguity ([pk]~ [kk]~ [kp]), thus contributing to perceptual place assimilation. Further research is needed to determine whether different degrees of overlap in the /pk/ clusters may have different perceptual consequences.

In sum, the current results suggest that gestural overlap is in fact an important factor in perceptual place assimilation. Whether partial gestural reduction can lead to perceptual place assimilation cannot be investigated on the basis of Korean. That overlap and reduction may both play an important role and in fact interact in perceptual place assimilation is, however, suggested by work by Surprenant and Goldstein (1998) and Chen (2003).

The finding that the Korean labial reduction seems to be categorical, applying at morphological boundaries within a prosodic word and not across words, suggests that the place assimilation rule is lexical (Kiparsky 1985, Mohanan 1995). Further evidence for its lexical status comes from the finding that it is not fully productive — if it were postlexical, it would be expected to occur 'across-the-board' in matched /pk/ clusters of nonsense words (Son 2004). Yet on the other hand, there is some evidence for its postlexical status as well: the process is variable in its occurrence, possibly style- or rate-related (Kim-Renaud 1991). Also Jun (1995, 1996) showed that it was rate-dependent (though not for all subjects, as was the case in our data). Further, the process is not clearly accessible to native speaker intuitions, another property commonly attributed to postlexical processes (cf. Mohanan 1995). Based on our informal observations naïve Korean speakers seem to be fully unaware of the process. These disparate lexical and postlexical characteristics of the Korean /pk/ assimilation suggest that the process is a change in progress, gradually developing its lexical status. The trigger that initiated this change, we propose, is gestural overlap and its perceptual consequences. The labial gesture, strongly overlapped by the dorsal gesture produced by a given speaker, could have exceeded some perceptual threshold (Browman and Goldstein 1992a) and mistakenly be interpreted by a listener as gradiently or fully reduced (see Chen 2003). Through multiple speaker-listener interactions and mis-imitations, such gradient reduction could have led to the categorical disappearance of the labial gesture in /pk/

cluster, thus resulting in the categorical, yet not fully completed lexical place assimilation process.

Importantly, the overlap-based approach provides a plausible account of cross-linguistic variability in place assimilation. Languages are known to differ widely in the degree of overlap they exhibit in consonant clusters; moreover, the degree of overlap in a given language may vary depending on consonant places of articulation (Zsiga 2000; Chitoran, Goldstein, and Byrd 2002). Place assimilation as a lexical process might, therefore, be potentially more likely to develop in languages with relatively higher degrees of overlap (e.g. in Korean and English as opposed to Russian and Georgian). In a given language, place assimilation may be expected to develop in clusters with relatively higher degrees of overlap, with greater perceptual consequences for some places of articulation than for others (e.g., coronals vs. labials; Byrd 1992). Gestural overlap should thus be regarded as an important factor in the evolution of place assimilation.

Appendix

Table 6. False alarms and hits (%) for the overlapped /pk/ cluster by monitoring condition for English listeners.

overlapped /pk/	Monitoring Block			
	k1	k2	p1	p2
English Listeners	% false alarm	% false alarm	% hit	% hit
1	33.3	33.3	60.0	16.7
3	20.0	0.0	100.0	16.7
4	40.0	93.3	33.3	50.0
5	40.0	33.3	66.7	0.0
6	53.3	26.7	73.3	50.0
7	100.0	40.0	0.0	8.3
8	33.3	33.3	0.0	0.0
9	46.7	53.3	33.3	0.0
10	100.0	20.0	60.0	25.0
11	33.3	13.3	60.0	33.3
12	40.0	66.7	6.7	8.3
13	86.7	40.0	33.3	66.7
15	53.3	33.3	93.3	8.3

Table 7. False alarms and hits (%) for the overlapped /pk/ cluster by monitoring condition for Korean listeners.

overlapped /pk/	Monitoring Block			
	k1	k2	p1	p2
Korean Listeners	% false alarm	% false alarm	% hit	% hit
1	73.3	86.7	0.0	0.0
2	46.7	6.7	20.0	80.0
3	33.3	26.7	80.0	40.0
4	26.7	73.3	33.3	73.3
5	13.3	46.7	66.7	73.3
6	86.7	73.3	13.3	0.0
7	100.0	100.0	26.7	13.3
8	80.0	26.7	6.7	80.0
9	60.0	66.7	46.7	66.7
10	100.0	73.3	6.7	0.0
11	0.0	0.0	100.0	100.0

Notes

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1. The difference in carrier phrases has no further relevance; it was changed to a shorter phrase in order to save experiment time.

2. The accusative marker /ɨl/occurring at the word boundary between /Vp/ and /kV/ was omitted, both in the current study and in Jun (1996).

3. For K1, 14 repetitions per sentence were obtained.

4. While the range of percentages of the effective maximum velocity for constriction degree may seem comparatively high, these speaker-specific threshold values best captured the movement onset, target achievement, and offset release in a comparable fashion.

5. We are much indebted to Sun-Ah Jun for advice on the prosodic grouping analysis.

6. A reviewer expressed the concern that the perceptual ambiguity may be a result of a response bias caused by the subjects always seeing an orthographic representation of the sound they are monitoring for on the screen. Within a subject, a potential response bias introduced by the letter on the screen or true perceptual ambiguity generating hits and false alarms equally cannot be distinguished. However, a response bias introduced by the letter on the screen would be expected to affect all conditions equally if indeed the ambiguity was merely a result of experimental setup. The only condition that generated response ambiguity in the 50% range was overlapped /pk/. For the control conditions as well as the reduced /pk/ conditions, for English listeners on average about 20% false alarms and 80% hits were recorded (Korean listeners: 25% false alarms, 72% hits for controls; 10% false alarms, 70% hits for reduced /pk/). This 20% -25% false alarm rate may possibly reflect a slight monitoring bias. However, for overlapped /pk/, there were on average 47% false alarm and 54% hit rate (English listeners; Korean listeners: 55% false alarms, 43% hits), showing a marked difference to the control tokens and reduced tokens. Further it should be pointed out that the observed within-subject ambiguity (i.e., both hit and false alarm responses) only held for some subjects. Some subjects perceived overlapped /pk/ predominantly as [k], others mostly as [p], yet still others vacillated between [p] and [k] responses. This overall pattern speaks against the ambiguity being a mere artifact of the monitoring instructions. It was overall also not the case that the perceptual ambiguity was apparent only in the first block of stimulus exposure or, alternatively, increased with increasing exposition to the tokens. For some subjects, indeed the d' values of the first two monitoring blocks (for convenience referred to as p1, k1) and the last two monitoring blocks (p2, k2) show considerable differences. The most extreme change was exhibited by English listener S7 for overlapped /pk/ shows 100% false alarms and no hit responses (d'=-4.65) for the first two monitoring blocks (p1, k1), but during the second monitoring block (p2, k2) she gave an similar number of false alarm and hit responses during both conditions (d' = 0.34). English listener S10, however, showed a different pattern in displaying a considerable shift between monitoring blocks p1, k1 (d'=-2.07) and monitoring blocks p2, k2 (d'=1.95), yet this was not a shift from unambiguous to ambiguous response. Also decrease in ambiguity could be observed between the monitoring blocks in other subjects (e.g., Korean S3 overlapped /pk/, d'(p1, k1) =-0.76 vs. d'(p2, k2)= 2.34).

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