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Perception of /dl/ and /tl/ clusters: A cross-linguistic perceptual study with French and Israeli listeners

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ABSTRACT

French listeners tend to hear illegal utterance-initial /tl/ and /dl/ clusters as /kl/ and /gl/, respectively, when speech is produced by French speakers [1, 5]. We re-examined this phenomenon, once called "phonotactic perceptual assimilation," in a cross-linguistic design using Modern Hebrew. In Hebrew, virtually all the obstruent-liquid clusters are permissible, including /dl, tl/. French and Israeli listeners were tested on their discrimination performance for the /dl/-/gl/ and /tl/-/kl/ contrasts, using monosyllables such as /tla, kla/ produced by a native speaker of Hebrew. French listeners showed substantial difficulty at discriminating these contrasts –especially /tl/-/kl/– whereas Israeli listeners experienced a slight difficulty only for /tl/-/kl/. French listeners categorised as velar the initial consonant of the /tl/ items and, but much less often, that of the /dl/ items. Altogether then, the /tl/-to-/kl/ perceptual assimilation is largely language-specific. Yet, it might be partly determined by universal perceptual constraints that seem to emerge in Modern Hebrew.

1. INTRODUCTION

Many findings in the field of non-native speech perception have shown that the perception of speech segments (i.e., consonants and vowels) is determined by both language-specific and language-universal constraints. For example, countless studies have probed Japanese listeners' deafness to the English /r/-/l/ distinction. This "deafness" is a reflection of both the Japanese phonological system and of the phonetic proximity of English /r/ and /l/, as the much lesser deafness of Japanese listeners to the French /r/-/l/ contrast suggests: French /r/ and /l/ are phonetically more contrasted than their English counterparts [2].

Recently, attention has been drawn to the role of phonotactic constraints in the perception of *sequences of speech sounds*: While new experimental data [3] reassessed Polivanov's observation that Japanese listeners hear a vowel in English *drama* between /d/ and /r/, the perception of /dl/ and /tl/ in French was recently found to give rise to perceptual assimilation [1]. These clusters are illegal word-initially in many languages, including French. French speakers' utterances beginning with /dl, tl/ were shown to be often misheard by French listeners as beginning with /gl, kl/ in the study mentioned above.

This work, however, left some issues unaddressed. First, the stimuli were produced by native speakers of French with no knowledge of any language allowing word-initial /dl/ or /tl/. Conceivably then, the phonetic-acoustic quality of the stimuli was not exactly dental, as it is unusual for French speakers to utter /dl/ or /tl/. Acoustic measurements and perceptual assessment of the dental quality of the initial consonant in the /dl, tl/ stimuli suggested that this was not the case. However, a more direct way to control for the 'correct' articulation of /dl/ and /tl/ stimuli is to use a language that allows /dl, tl/ word-initially. Second, the 'perceptual assimilation,' or, as we might call it, the 'dental-to-velar illusion' in [1] has been interpreted as pre-lexical in nature, reasoning that only non-words had been used, and that the illusion was strongest in a presumably 'on-line' phoneme detection task. But none of these arguments are sufficient to dismiss an interpretation in terms of *lexical* influence, such as lexical feedback. This is all the more plausible because the stimuli used were two-syllable non-words, which –except for the initial cluster– followed the phonotactic constraints of French, and indeed sounded like French words. The cross-linguistic approach of using non-native stimuli that do not 'sound French' will thus be useful to probe the pre-lexical versus lexical nature of the dental-to-velar illusion. Finally, we might wonder whether this illusion is specific to French –and possibly to other languages where word-initial /dl, tl/ are banned– or reflects a universal trend. Again, the cross-linguistic approach can be helpful here, telling us whether native listeners of a language which allows /dl, tl/ show a tendency to mishear, for example, /tl/ as /kl/.

The present study was designed to address the issues mentioned above, using speech materials produced by a native speaker of Hebrew. In Hebrew, virtually all the obstruent-liquid (OBLI) clusters are permissible, including /dl/ and /tl/. The phonetic-acoustic characteristics of the velar and dental stops as well as of the /l/ and /r/ sounds are similar in French and Hebrew. The R sound, which we use here to contrast with /l/, has been described as a uvular approximant/fricative in both languages [4]. These features made Modern Hebrew a rather ideal candidate to

ISBN 1-876346-48-5

compare with French.

Israeli listeners, whose mother tongue was Hebrew, and naive French listeners were tested on their perception of OBLI contrasts that are permissible in both languages (/tr/-/kr/ and /dr/-/gr/) against those that are permissible only in Hebrew (/tl/-/kl/ and /dl/-/gl/), presented in CCV syllables with the vowels /a/, /i/, and /u/. The -/r/ clusters served as a baseline to judge the putative difficulty with -/l/ clusters. This applies to Israeli listeners as well, and might tell us whether there is an intrinsic, universal difficulty with the dental (coronal) plus /l/ clusters. French listeners also had to categorise the initial consonant of stimuli such as /tla/, /kla/, /tra/, or /kra/. The predictions were straightforward. If dental-to-velar perceptual assimilation also obtains with Hebrew stimuli, the /tl/-/kl/ and /dl/-gl/ contrasts should be difficult compared to /tr/-/kr/ and /dr/-/gr/. For French listeners, /tl/-/kl/ should be even harder than /dl/-/gl/. (Perceptual assimilation has been observed as stronger for /tl/ than for /dl/ [1, 5].) Categorisation should predict discrimination performance [6, 7, 8] in that discrimination difficulty should correlate with the bias to judge Hebrew /dl, tl/ as velar-initial.

2. DISCRIMINATION

We first looked at the discrimination of Hebrew /dl/-/gl/ and /tl/-/kl/ clusters by French listeners vs. Israeli native speakers of Modern Hebrew. If the Hebrew /dl, tl/ clusters give rise to dental-to-velar perceptual assimilation, French listeners should hear them as close to /gl, kl/ and have trouble to discriminate the Hebrew /dl/-/gl/ and /tl/-/kl/ contrasts. The Hebrew /dr/-/gr/ and /tr/-/kr/ contrasts were used to control whether French listeners can discriminate Hebrew dental-velar contrasts in a "legal" liquid context and correctly interpret the /dr, tr/ and /gr, kr/ clusters as dental and velar, respectively. Israeli listeners served as control listeners and were not expected to experience difficulty with contrasts that are phonological in Hebrew.

Stimuli and design. 24 monosyllables were constructed by crossing the clusters /dl, tl, gl, kl, dr, tr, gr, kr/ (all legal word-initially in Hebrew) with the vowels /a, i, u/. The onset clusters were thus composed of a dental or velar plosive, voiced or unvoiced, followed by the liquid /l/ or /r/. A randomised list containing eight tokens of each item was recorded on DAT by a male native speaker of Hebrew, then transferred to computer (16 kHz sampling rate, 16 bit precision). For each of the 24 items, four tokens (out of eight recorded tokens) were retained so as to balance as well as possible syllable duration and F0 contour among the sets of items to be contrasted (e.g., the /gla, dla/ set). Phonetic data are very scarce with respect to Hebrew. We therefore measured VOTs and spectral centre of gravity at release burst for the retained tokens' initial consonant according to voicing, place, and liquid context (Table 1). Interestingly, it appears that the voicing contrast is phonetically pre-voiced vs. long lag voiceless, and that the dental-velar contrast is cued by both longer VOT and lower burst spectrum for velars. Yet, this is observed with one male speaker aged 35 years: Of course, further phonetic investigations are needed to confirm the observed trends.

	Voiced				Voiceless			
	/dl/	/gl/	/dr/	/gr/	/tl/	/kl/	/tr/	/kr/
VOT	-126	-99	-98	-86	60	91	50	98
SCG	3812	3561	3906	3557	3867	3767	3918	3602

Table 1: Acoustic measurements on Hebrew stimuli: VOT (ms) and Spectral Centre of Gravity (Hz) of the stops.

The retained tokens were used to make up AXB triplets where A and B differed by place of articulation (velar vs. dental). To illustrate, 32 triplets were constructed using tokens of /gla/ and /dla/, with 8 combinations of tokens for each type order (AAB, ABB, BAA, and BBA) so that each token appeared equiprobably in each position and was never repeated in a given triplet. In all, 384 triplets were constructed by varying vowel, initial consonant voicing, and liquid (32 combinations x 3 vowels x 2 voicings x 2 liquids) and were presented in random order to participants in the test phase: 32 blocks of 12 AXB trials. The test phase was preceded by a training phase of 10 other AXB trials, three of which were 'easy' in that A and B differed in both initial consonant and liquid. The interstimulus interval was set to 1 s, the intertrial interval to 4 s, and the interblock interval to 8 s. Participants were allowed to pause midway in the test phase.

Procedure. Participants were instructed to press one of two response buttons at each AXB trial: a button labelled '1' if they thought that X was closer to A than to B; a button labelled '3' if they thought X was closer to B. They were instructed to respond for each trial even if they had to "guess" and to respond as fast as possible, as soon as they were confident about their response. Importantly, this entails no speed restriction (such as would be induced by the instruction of not responding before B). Thus, when participants are quite confident, they may respond even before B (actually performing an AX-like speeded task in this case). This aspect has proved useful to enhance RT differences in speeded AXB tasks [2]; one drawback is that within-group RT variability may be large. We call this variant of the AXB discrimination procedure the 'free RT' speeded AXB paradigm.

Participants. Thirteen French students at Paris V University (mean age 22, age range 19-25) and 12 Israeli people –native speakers of Hebrew recruited in Paris (mean age 23, age range 21-29)– participated in the experiment for a small amount of money. The data for one French and one Israeli participant were not retained (miss rate greater than 10% vs. 0.2% for the other participants).

Results. Figure 1 shows the performance of the French vs. Israeli listeners in terms of percent correct discrimination. Figure 2 shows the RT data. Statistics run on these data show that French and Israeli listeners performed at ceiling for the control contrasts /gr/-/dr/ and /kr/-/tr/ involving legal clusters in both French and Hebrew. For French participants, performance dramatically dropped down for the -/l/ cluster contrasts, especially for the /kl/-/tl/ contrast

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(64%) significantly harder than /gl/-/dl/ (77%), $F(1, 11) = 13.70$, $p < .005$. For Israeli participants, performance was slightly, yet significantly lower for the /kl/-/tl/ contrast than for the others, $F(1, 10) = 15.27$, $p < .005$.

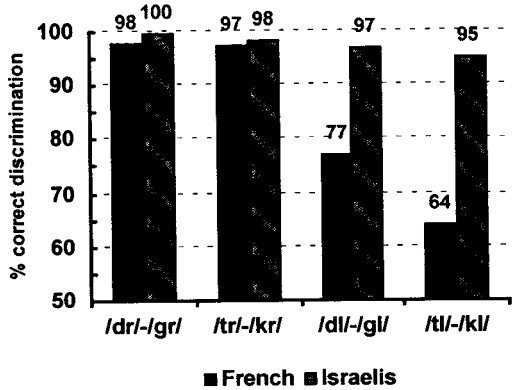

Figure 1: Percent correct discrimination according to contrast type for French vs. Israeli participants

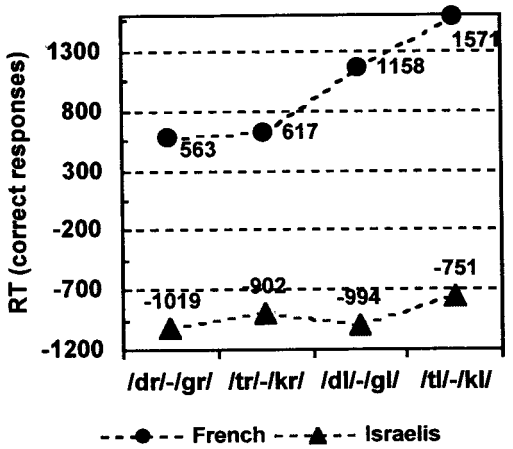

Figure 2: RTs for correct discrimination responses

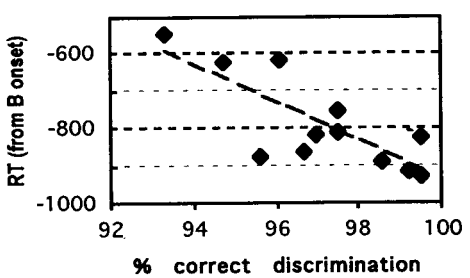

Figure 3: RT x Percent correct correlation (Israelis): one data point per contrast (4 cluster types x 3 vowels)

The RT data closely paralleled the percent correct data with longer RTs for poorer discrimination: the (negative) correlation between RT and percent correct discrimination was highly significant, even for the Israeli participants, although they exhibited a very restricted range of percent correct variation (French: $r(10) = -0.96$, $p < .0001$; Israelis: $r(10) = -0.79$, $p < .005$). This is illustrated in Figure 3 (Israeli participants). Worth to note are the significantly longer RTs for /kl/-/tl/ (correct responses) than for any other contrast for both French and Israeli participants (e.g., $F(1, 10) = 22.40$, $p < .001$ for Israeli participants).

To summarise, French participants had great trouble to discriminate the Hebrew /gl/-/dl/ and /kl/-/tl/ contrasts, and even more so for /kl/-/tl/, as conjointly shown by RT and percent correct scores. Surprisingly, Israeli participants also had some trouble with the /kl/-/tl/ contrast, although clearly much less than French subjects. We turn now to the categorisation data.

3. CATEGORISATION

The discrimination data for French participants was quite consistent with the prediction that French listeners would hear Hebrew /dl, tl/ as /gl, kl/. A categorisation test bearing on the initial consonants of the same items as those used in the discrimination test should reinforce that prediction, and, perhaps, confirm the asymmetry found between the /dl/ and /tl/ clusters. The categorisation test was given only to French participants (the same as in **2.**).

Stimuli and design. Each of the 24 /dl, tl/ syllables from the discrimination test (2 voicings x 3 vowels x 4 tokens) were used twice in the test phase, making 48 trials. The other 72 syllables (24 /gl, kl/, 24 /dr, tr/, and 24 /gr, kr/) were used only once. The test phase (120 trials) was preceded by a short training phase of 16 trials, which included two /dl/ and two /tl/ trials.

Procedure. For each trial, participants were first presented a given syllable twice in a row. They were instructed to identify its *initial consonant* by choosing one of 10 possible consonants illustrated by French 'keywords' (*paon, temps, Caen, banc, dent, gant, sang, Zan, rang,* and *lent* for /p/, /t/, /k/, /b/, /d/, /g/, /s/, /z/, /r/, and /l/, respectively). After their choice was made (without time pressure), participants had to rate how well their choice matched the syllable just presented, using a 1-5 scale. The next trial was then administered until the test phase was completed.

Results. For all the legal clusters, such as /gl, kl/, /gr, kr/, and /dr, tr/, the rate of confusion with respect to place of articulation was negligible. For all the stimuli, including the critical /dl, tl/ stimuli, the rate of voicing confusion was negligible too (below 0.5%). We therefore focused on the place confusions that occurred for the critical stimuli. Figure 4 shows the raw percentages of place responses according to the Hebrew /dl/ and /tl/ clusters. The combined percentage and rating data, that is, the 'fit index' data [6] yielded essentially the same pattern.

ISBN 1-876346-48-5

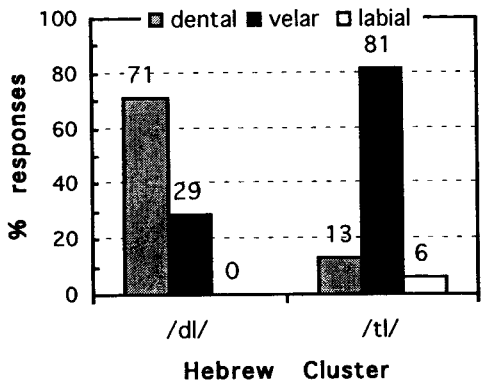

Figure 4: Categorisation data: French listeners' judgments on the initial consonant of the Hebrew /dl, tl/ clusters.

Velar responses for the /dl, tl/ clusters were much more frequent than for /dr/ or /tr/. Yet, there was an asymmetry between the /dl/ and the /tl/ clusters: Velar responses were more frequent for the /tl/ than for the /dl/ clusters (81.3% vs. 29.2%), $F(1, 11) = 61.57$, $p < .0001$. (Statistics run on the fit index data yielded the same result.) This asymmetry is in line with the differential performance in the discrimination of /dl/-/gl/ and /tl/-/kl/: the harder the contrast, the more velar judgments for the dental -/l/ clusters. Indeed, the discrimination performance for the critical contrasts correlated negatively with the rate of velar judgments for the critical /dl, tl/ clusters (Figure 5), $r(22) = 0.793$, $p < .001$.

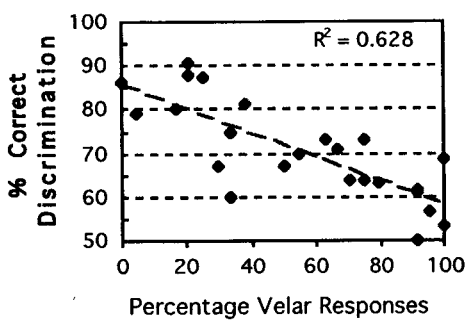

Figure 5: Discrimination x Categorisation Correlation

To summarise, the categorisation data clearly confirm our interpretation of the discrimination data. French listeners hear Hebrew /tl/ as /kl/ and, to a lesser extent, /dl/ as /gl/.

4. CONCLUSIONS

This study confirmed the robustness of the dental-to-velar perceptual assimilation found for French listeners presented with the word-initially illegal /dl/ and /tl/ clusters. The various concerns about the published data [1] showing *within-language* perceptual assimilation have been dealt with. First, the phenomenon is not reducible to a pronunciation difficulty for French speakers; syllables such as /tla/, /dlu/ pronounced by a native speaker of Hebrew, a language which allows word-initial /dl, tl/, give rise to the same pattern of dental-to-velar assimilation as has been previously observed in [1]. Second, the use of monosyllables in a cross-linguistic experimental design makes it unlikely that the effects obtained be lexical in nature. The dental-to-velar perceptual assimilation more likely occurs at a pre-lexical level of processing.

An interesting aspect of the results is the asymmetry in the treatment of /dl/ and /tl/. Were the dental-to-velar effect determined uniquely by the phonotactic constraints of French, such an asymmetry should not be observed: /tl/ and /dl/ are equally illegal word-initially. The reason why /dl/ gives rise to a lesser illusion than /tl/ is probably to be found in phonetic rather than phonemic differences.

Finally, a surprising finding is that not only French listeners (and probably native listeners of any language in which word-initial /dl, tl/ are not permissible), but also Israeli listeners –native speakers of Modern Hebrew– seem to experience some difficulty with /tl/ in utterance-initial position: There might be a universal perceptual difficulty intrinsic to this particular cluster.

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ISBN 1-876346-48-5