Perception of time-varying coarticulatory cues: nasal and labial coarticulation in French

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In French, fine-grained differences in coarticulatory timing for both nasality and lip rounding provide perceivable information to listeners for phoneme identification and disambiguation [1, 2, 3]. However, there are known differences in the temporal extent of these phonetic parameters: while anticipatory lip rounding was found to be quite extensive and variable [4], nasal coarticulation is rather constrained (e.g., [5]). This within-language difference affords the unique opportunity to test whether these inter-articulator production differences are directly reflected in listeners' perceptual patterns. The present study examines the use of coarticulatory timing cues by comparing production and perception of anticipatory nasalization and anticipatory lip rounding in the same speakers. We ask whether French listeners are sensitive to fine-grained differences in coarticulatory timing during spoken-word recognition. Listeners' responses should then systematically vary with coarticulatory onset for both articulators.

16 French speakers participated in a production task (reading) and perception experiment (visual-world paradigm). Recorded stimuli, which were embedded in a carrier phrase, were nasal/oral pairs (VN/VC) and rounded/unrounded front vowels in CV sequences (Table 1). The onset of the target consonant served as alignment point (zero) relative to which the onset of coarticulation was determined algorithmically as a point in signal divergence (nasal intensity/lip spread) between a given nasal/oral (rounded/unrounded) minimal pair. An equal number of extensive and constrained items (in 1st and 4th quartile of group-level onset distribution) were sampled for each articulator as perception stimuli. The extensive category's mean onset was -288ms for lip rounding and -154ms for nasality. The constrained category's mean onsets were -110ms and -47ms respectively. Participants' eye movements were tracked during a categorization task, where they saw written minimal pairs on a screen and had to click on the word they heard in an audio containing the whole carrier phrase. Target fixation probability over time (5ms bins) was calculated with Growth Curve Analysis (GCA) [6]. One model per articulator was computed with a fixed effect of coarticulation type (extensive, constrained), functions for time ($time^n$, n = [1,7]) and their interactions.

GCA curves for nasality show that in the extensive condition target fixations rise 50ms after target onset (Fig. 1, A). Considering 200ms for saccade execution [7], the results suggest that fixation responses align with the onset of coarticulation (here: -154ms prior to the target sound). Surprisingly, responses in the constrained condition statistically converge with the extensive condition (Fig. 1, C), and occur thus too early to be signal-driven. However, overall, listeners are sensitive to nasal coarticulation cues when they become available in the signal. For lip rounding, target fixation proportions in the extensive condition start increasing at target onset (Fig. 1, B), suggesting a listener response slightly delayed relative to the coarticulation onset (here: -288ms). The constrained condition's target fixations rise at 100ms into the target (Fig. 1, B), being in line with the coarticulation onset (here: -110ms). Moreover, target fixations in the constrained condition significantly diverge from the extensive condition shortly after target onset (Fig. 1, D), suggesting an earlier use of extensive than constrained coarticulation.

The results suggest that French listeners are sensitive to extensive nasal and labial coarticulatory cues as soon as they are available in the signal. Perceptual patterns reflect the temporal differences in coarticulatory extent in production for both articulators, although anticipatory rounding is prone to be more variable. In our discussion we will further address whether speakers' individual coarticulatory behavior predicts their perceptual sensitivity.

Table 1: *Example minimal pairs of the nasality and lip rounding corpus. The carrier phrases are "Je dis à Cléo X samedi" (nasality) and "Mais elle déclarait X par hasard" (labiality).*

	Example & transcription
Nasal corpus	l'année, [la.ne] vs l'athée, [la.te]
Labial corpus	Caire, [kɛʁ] vs. cœur, [kœʁ]

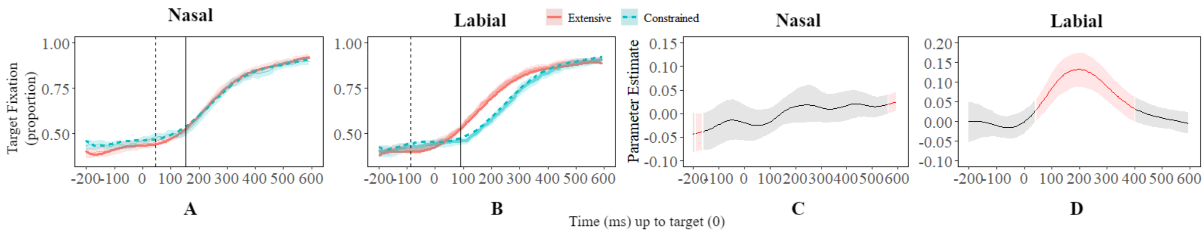

Figure 1: *Growth curve analysis for extensive (red solid line) and constrained (blue dotted line) tokens for nasal (A) and labial (B) perception. Mean fixation proportions in opaque colors. Estimated earliest point of reaction for the extensive (vertical dashed lines) and constrained condition (vertical solid lines). Divergence in proportion of fixation between extensive and constrained coarticulation for nasal (C) and labial (D) coarticulation. Significant differences are marked in red. In all plots, zero marks the acoustic onset of the target consonant/vowel.*

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