Coarticulation and articulatory compensations studied by dynamic MRI

D.Demolin[1], M George[2], V Lecuit[2], T.Metens[3], A Soquet[2] and H Raeymaekers[4]*

Department of Linguistics[1]
Laboratory of Experimental Phonetics[2]
Magnetic Resonance Unit, Hopital Erasme[3]
Université Libre de Bruxelles, Brussels, Belgium
Philips Medical Systems (4) Brussels, Belgium[4]
Tel. +32 2 650 45 07, E-mail: ddemoli@ulb.ac.be
[*] Collaborateur scientifique – FNRS

ABSTRACT

This paper presents an ultra fast implementation of Turbo Spin Echo (TSE) to achieve continuous monitoring of the vocal tract with an actual time resolution of 4 images per second. We present preliminary results of two experiments involving coarticulation and articulatory compensations.

1. INTRODUCTION

Magnetic Resonance (MR) allows imaging of the vocal tract during phonation (1,2). Recently, simultaneous MR acquisition of multi oblique slices in a sole 14 sec acquisition provided an improved generation of area functions, which is an important step in the study of the relation between vocal tract geometry and speech acoustics. Similarly, the acquisition of parallel joints slices of 1 mm^2 resolution was also possible. Sustained phonation was required during acquisitions (14 sec) (3, 4, 8). Nevertheless, these experiments were restricted to the study of oral or nasal vowels, because of the low temporal resolution. Progress made to increase the temporal resolution are limited by low Signal-to-Noise ratio and by susceptibility artifacts when fast gradient echo techniques are involved. In the present work, we adapted an ultra fast implementation of Turbo Spin Echo (TSE) to achieve a dynamic continuous monitoring of the vocal tract with an actual time resolution of 4 images per second. We aimed to show that this technique can be used to study the relative movements of the main articulations involved in speech production i.e. lips, tongue, larynx, lower jaw and velum.

2. MATERIALS AND METHODS

Four normal volunteers (2 males and 2 females) were asked to pronounce slowly, in two different experiments, the following sequence of non sense words and segments: [tagy], [tyga], [iui], [iai], [ieaou] and [beben]. Compensatory movements of the tongue and of the larynx were studied, with non sense words and segments similar to those used for the coarticulation experiments, when the lower jaw is blocked during phonation. For both experiments, speakers were asked to pronounce words and segments slowly, so as to visualize the movements of the main articulators involved in speech production.

MR imaging was performed with the TSE Lolo sequence (9). One sagittal T1-weighted section of 6 mm thickness was continuously acquired during at least 20 sec, using a quadrature neck coil at 1.5 T (Philips Gyroscan ACS NT, Best, The Netherlands). The acquisition was implemented with the following parameters: TR=250 ms, TE=30 ms, q=60°, ESP=7.8 ms, ETL=19 and 60% Partial Fourier acquisition, Field of View=300 x 150 mm with a 32 x 128 Matrix. The TSE Lolo sequence is designed such that the initial 60° and the subsequent 180° refocusing pulses excite perpendicular slabs, resulting into an intersecting slice, free of foldover artifacts and without compromising the spatial resolution.

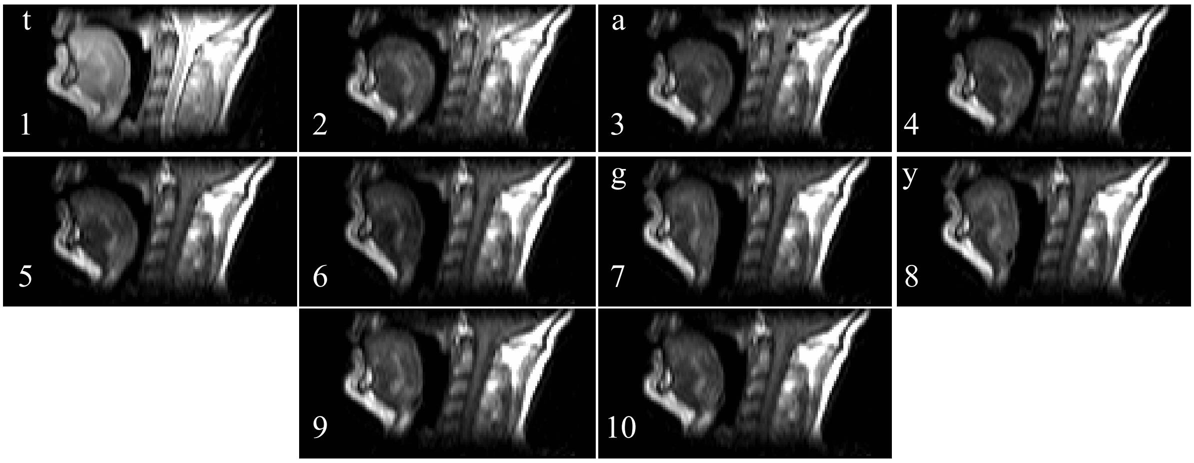

Figure 1: [tagy] uttered by male speaker 1.

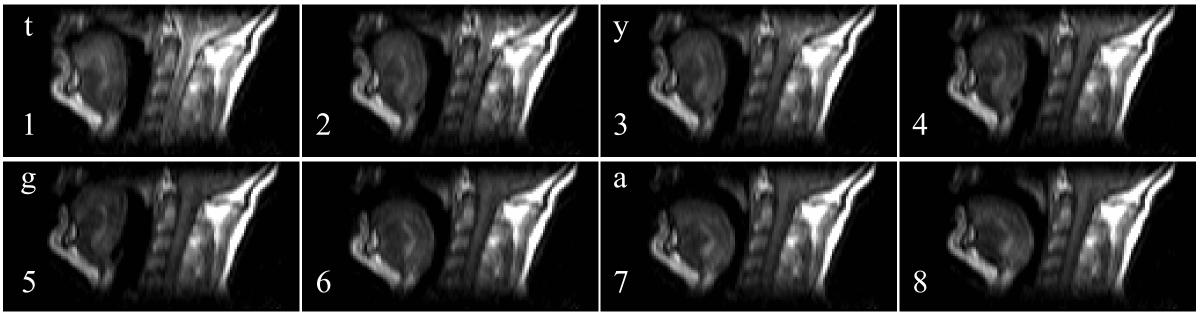

Figure 2: [tyga] uttered by male speaker 1.

3. RESULTS AND DISCUSSION

3.1. Experiment 1

We applied TSE Lolo sequence to observe coarticulatory factors in pseudo-words [tagy] and [tyga]. In [tagy], the first image shows the segment [t], while the following images show movements of articulators going to the target of segments [a], [g], [y]. This sequence, presented in figure 1, shows the gradual lowering of the tongue moving from the alveolar closure of [t] (image 1) to the low tongue position of [a] (image 3), then there is a raising of the tongue body to the velar place of articulation for the velar consonant [g] (image 7) it can also be observed that lips rounding begins simultaneously in anticipation of the following rounded vowel [y] (image 8). This anticipatory effect is not observed on [tyga] (figure 2), the lowering of the jaw and lip opening being realized after occlusion release for the production of the open unrounded vowel [a].

3.2. Experiment 2

This experiment was designed in order to observe articulatory compensations when subjects are holding a 2 cm diameter plastic water bottle between their teeth. Subjects were first asked to repeat for 6 seconds a sequence of vowels [uiu] without interruption. Male speaker 1 showed a modification of the larynx position, high for [i] and low for [u]. This difference can be observed on images 6 and 12 in figure 3. When moving from [i] to [u], lip rounding gradually takes place as can be observed on images 9 to 12 of figure 3.

The amplitude of larynx lowering during the transitions between [i] and [u] is smaller for speaker 2 than for speaker 1 as can be observed on figure 4, images 6 to 11. For the same transition the lip rounding is realized between images 8 to 11 on figure 4.

Figure 5 shows the articulatory movements made by male speaker 2 when realizing the sequence [uiu] holding a water bottle between his teeth. This shows that the larynx is maintained in a stable position and that when the lower jaw is blocked, there is a deformation of the tongue which shows that only tongue body is moving from front to back in the vocal tract. Even if the lips are neutralized by the bottle there is a perceptible lip rounding when the tongue is moving to the [i] position to the [u] position as can be seen on images 6 to 12 of figure 5.

4. CONCLUSION

Subsecond MRI technique has allowed to explore movement of articulators involved during normal speech production in several plans (coronal, transversal, oblique). In order to validate the technique we have observed the following parameters: tongue body movement which is easily distinguished when it is going from vowel to other in sequences such as [ieaou]; the vertical displacement of the larynx; the opening and closure phase of the velum when speakers were pronouncing the non-sense word [beben]; lip rounding and jaw movements. The technique is very promising to describe speech production processes but also to study coarticulation and articulatory compensations.

However there is still a major problem, in addition to known limitations of MRI. It is still not possible to identify the sound on the LOLO sequences. One possibility to solve the problem would be to use an isolated pneumatic mask during the recordings.

When this problem will be solved, it will be possible to study anticipation and retention effects between the consonant and the vocalic context of V_1CV_2 sequences, and to compare predictions made by different models of coarticulation (5, 6) with measurements on observed sequences. This new technique is also an interesting tool to study and replicate compensation phenomena (7).

5. REFERENCES

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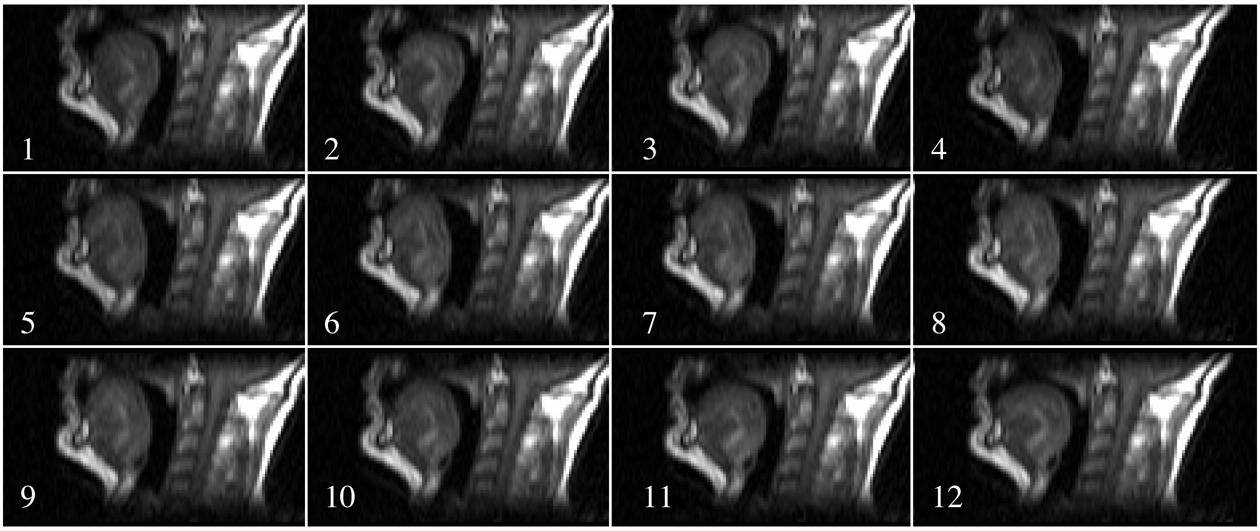

Figure 3: [uiu] uttered by male speaker 1.

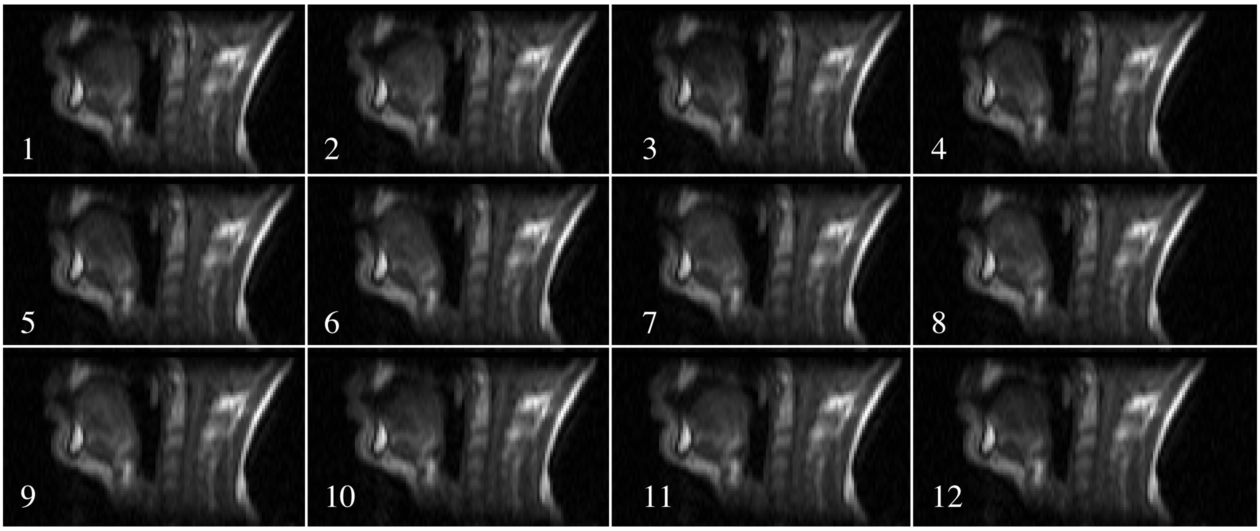

Figure 4: [uiu] uttered by male speaker 2.

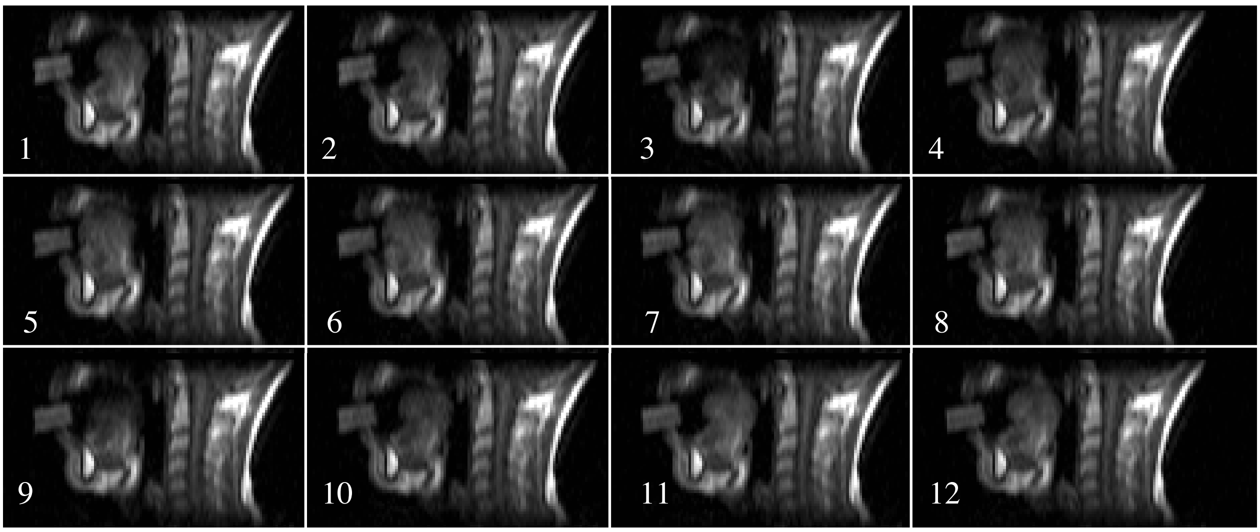

Figure 5: [uiu] uttered by male speaker 2 with bite block.