SECTOR: Higher Education Institution

LOCATION: France, Grenoble

RESEARCHER PROFILE:
□ First stage researcher,

INSTITUTION: Univ. Grenoble Alpes, University of Innovation

One of the major research-intensive French universities, Univ. Grenoble Alpes\(^1\) enjoys an international reputation in many scientific fields, as confirmed by international rankings. It benefits from the implementation of major European instruments (ESRF, ILL, EMBL, IRAM, EMFL\(^2\)). The dynamic ecosystem, grounded on a close interaction between research, education and companies, has earned Grenoble to be ranked as the 5th most innovative city in the world. Surrounded by mountains, the campus benefits from a natural environment and a high quality of life and work environment. With 7000 foreign students and the annual visit of more than 8000 researchers from all over the world, Univ. Grenoble Alps is an internationally engaged university.

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* ESRF (European Synchrotron Radiation Facility), ILL (Institut Laue-Langevin), IRAM (International Institute for Radio Astronomy), EMBL (European Molecular Biology Laboratory), EMFL (European Magnetic Field Laboratory)

Key figures:
- + 50,000 students including 7,000 international students
- 3,700 PhD students, 45% international
- 5,500 faculty members
- 180 different nationalities
- 1st city in France where it feels good to study and 5th city where it feels good to work
- ISSO: International Students & Scholars Office affiliated to EURAXESS

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\(^1\) Univ. Grenoble Alpes
MANDATORY REFERENCES:

IDEX PROJECT TITLE: Multidisciplinary Institute for Artificial Intelligence – Chair: Bayesian Cognition and Machine Learning for Speech Communication

SUBJECT TITLE: Deep Tongue: speech and predictive control of tongue movements by the brain

RESEARCH FIELD: Speech Motor Control, Motor Control, Control Theory, Cognitive Science, Machine Learning

SCIENTIFIC DEPARTMENT (LABORATORY’S NAME): GIPSA-lab

DOCTORAL SCHOOL’S: EDISCE (Cognitive Science)

SUPERVISOR’S NAME: Pascal Perrier & Pierre Baraduc

TYPE of CONTRACT: 3-year doctoral contract

JOB STATUS: Full time

HOURS PER WEEK: 35

SALARY: between 1770 € and 2100 € gross per month (depending on complementary activity or not)

OFFER STARTING DATE: November, 1st, 2020

SUBJECT DESCRIPTION:

I. Context

How do we talk? How do we successfully control a soft organ like the tongue, and produce complex series of short but recognizable speech sounds? With this thesis, we would like to tackle this question of speech motor control with a specific focus on the way planning and execution interact to achieve the expected somatosensory and auditory goals required for efficient speech communication. More specifically, we want to further test the assumption that the brain implements an internal model of the dynamics of the speech articulators in order to predict their instantaneous state, and integrates this prediction in real time with the noisy and delayed sensory feedbacks in order to ensure the correct pronunciation of sounds in all circumstances, while minimizing effort.

II. Basic hypotheses

Figure 1 – Current optimal planning and execution.

Top panel: Motor planning. Phoneme-related goals are specified and motor commands are inferred by optimization using a static internal model to map goals to via-points for the motor commands.

Bottom panel: Execution. Tongue postures reached for the phonemes (top), articulatory trajectories (left) and spectrogram of the produced speech (right) are depicted for an /aki/ sequence.
Our starting point is a model of speech production developed at GIPSA-lab over the last 20 years, called GEPPETO. This model associates a model of motor planning and a model of execution to generate articulatory movements and the corresponding acoustic and somatosensory signals (see Fig. 1; Perrier et al., 2005; Perrier & Ma, 2008).

Recently, GEPPETO has been implemented as a Bayesian model (Patri et al., 2015, Patri et al., 2019), in which (1) the phonemic sensory map, that associates phonemes with discrete sensory goals, consists of a number of phoneme-related Gaussian probability distributions in the somatosensory and auditory spaces, (2) the static internal model is a probabilistic mapping of the sensory consequences of motor commands, and (3) motor planning infers the optimal combination of phoneme-related motor commands using a maximum likelihood principle. This model has been shown to account properly for anticipatory coarticulation and vowel reduction phenomena associated with high speaking rate (Patri et al., 2015).

### III. Main tasks of the thesis project

#### III.1. Integrating a dynamic internal model

During the execution of the movement, the current GEPPETO model does not integrate any ongoing feedback information about the current state of the speech production system. It corresponds to a so-called pure feedforward model of speech production, in which execution is the exact consequence of original motor planning. There is no monitoring of whether the planned motor commands resulted in the intended sensory goals. This is a legitimate hypothesis for nominal speech production, which is a extensively learned skilled motor task in adults. However, it cannot account for speech development, compensation for perturbations, or adaptation to dramatic (e.g. surgical) changes in the speech production system.

Feedback is difficult to use efficiently for a speech motor controller, as neural delays are close to the duration of transitions between phonemes. If a discrepancy between expected and achieved state is detected, corrections would mainly apply to the forthcoming articulatory movements.

In this context, it has been proposed that the brain could rely on a so-called “internal feedback” (Wolpert et al., 1998) to predict with no delay the sensory consequences of the motor commands. In order to be useful, this internal prediction needs to correctly represent the dynamical properties of the peripheral system. This internal model is supposed learned during language acquisition in childhood.

The first task of the thesis work will be to integrate this internal model in GEPPETO as illustrated Fig. 2. External feedback is sent to the motor planning module with a long delay $T_{\text{ext}}$ and is processed for a posteriori corrections. The dynamical internal model computes the internal feedback with a short delay $T_{\text{int}}$, allowing to evaluate the probability of reaching the current sensory goal with the appropriate timing. If it is low, the motor commands at targets are re-planned for the whole sequence. This re-planning is based on predicted sensory outputs at the phoneme related targets only (in green) and can take two forms: 1) redefining the sequence of phoneme-related motor commands, if the predicted sensory features for the next phoneme are far from expected, or 2) increasing muscle force if articulatory movements are predicted to go toward the intended targets, but with incorrect timing.
III.2. Implementing an Optimal Feedback Controller

The approach described in Fig. 2 is not widespread in motor control research, as it is more commonly assumed the existence of an optimal feedback controller (OFC, Todorov & Jordan, 2002). In this scheme, external feedback is used to compute an internal estimate of the state of the system at each time step, which allows computing appropriate motor commands for the intended sensory goals. The motor commands are hypothesized to minimize a central cost (e.g. neuromuscular cost) while ensuring correct accuracy and precision (goal-related cost). There is no temporal dissociation between low-level (i.e. trajectory) planning and execution, since both are dynamically handled.

In order to contrast the predictions of both models, the second task of the work will be to implement an OFC in our framework (Fig. 3). This involves two crucial changes compared to the model of Fig. 2: (1) motor planning involves an optimization along the whole trajectory; (2) processing the internal feedback involves the integration of the whole time variation of the sensory variables (in green in the bottom left panel). Besides, special attention should be paid to optimizing the production of consonants, for which the dynamics of the language is clearly non-linear.

III.3. Evaluation of the two proposed models including internal feedback processing

Both models will be evaluated on two aspects. First, the production of stop consonants inside V₁CV₂ sequences will be considered. Proper articulator dynamics is crucial to create the short burst characterizing them: this makes such consonants a perfect benchmark to evaluate our models. Thanks to a coupling with an acoustic analog of the vocal tract, it is possible to precisely relate the time variation of the constriction size in the vocal tract with the intensity and duration of the noise burst. Starting from various combinations of motor control variables adapted to the production of correct tongue postures for V₁, C and V₂, both models will be used to search for the adequate motor commands for the production of stop consonants. This study can be seen as the simulation of the process underlying the acquisition of the appropriate control of a V₁CV₂ sequence during ontogenetic development.

Second, the impact of unexpected perturbations during the transition between two vowels will be investigated. Perturbations will be either mechanical (e.g. sudden freeze the jaw opening movement in the /i-a/ transition) or auditory (sudden formant shift). The amplitude and dynamics of the motor compensation produced by the two proposed models will be contrasted.
The modeling results of this PhD thesis will allow interpreting parallel experimental work by other members of the team on the online compensation of mechanical or acoustical perturbations during speech. This work will also provide the rationale for novel experiments, and guide the elaboration of more complex models integrating the coordination of additional articulators (lips, jaw, velum) as well as the laryngeal vibration source.

**Figure 3 – Optimal trajectory planning and Optimal Feedback Control during execution.**

*Top panel: Motor planning. It involves an optimization along the whole trajectory thanks to the use of an internal dynamical model.*

*Bottom panel, right: Execution (see Fig. 2).*

*Bottom panel, left: Internal simulation, with approximated articulatory trajectories on the left and approximated spectrograms on the right; the whole time variation of both the actual (blue arrows) and predicted sensory outputs (green arrows) are propagated back to the motor planning level, for on-line computation of the instantaneous motor commands.*

**IV. Bibliographic References**


ELIGIBILITY CRITERIA
- A Master’s degree (or be about to earn one) or a university degree equivalent to a European Master (5-year duration) in Control Theory, Cognitive Science, Computer Science, or Applied Mathematics.
- Advanced knowledge in (optimal) control theory + Solid skills in Machine Learning or probabilistic modeling (an affinity for cognitive sciences and speech sciences is welcome).
- Good programming skills (C/C++, Python, Matlab).
- Good oral and written communication in English.
- Ability to work autonomously and in collaboration with supervisors and other team members.

Applicants will have to send an application letter in English and attach:
- Their last diploma
- Their CV
- A short presentation of their scientific project (2 to 3 pages max)
- Letters of recommendation are welcome.
Applications will be evaluated as they are received: the position is open until it is filled.

Address to send their application:
Pierre Baraduc Pierre.Baraduc@grenoble-inp.fr
Pascal Perrier Pascal.Perrier@grenoble-inp.fr