Supplementary materials for 'The CARE approach to incorporating undergraduate research in the phonetics/ phonology classroom', by Christina Bjorndahl and Mark Gibson. *Language* 98(1).e1–e25, 2022.



# LESSON: HYPOTHESIS GENERATION

## Learning objectives/skill development

- Understand the existing state of knowledge regarding the problem at hand.
- Have sufficient background knowledge (i.e., command of relevant background literature).
- Understand how available methodologies may provide answers to research questions.
- Understand relationship between specific measures and hypotheses.
- Active engagement with complex material required in order to ask questions and formulate hypotheses
- Translation of vague ideas into quantifiable questions
- Creativity

## Mode of delivery

**Blackbox:** Blackboxing this activity may be advantageous if the students will be joining an ongoing project in the professor's lab/research project and the hypotheses are already generated. In this case, only the research-relevant skills may be developed if addressed by the professor in class.

**Simulation:** We chose this activity as a simulated learning activity because we wanted to control the study maximally in order to better plan ahead the types of activities and materials the students would need to carry out the project. Additionally, this activity develops both the research-relevant and transversal skills defined above while being able to maximally control the corpus that will be recorded.

**Full engagement:** It may be desirable in certain circumstances to allow the students to derive their own hypotheses depending on which skills the professor wants them to develop. In the case that the professor wants the students to derive their own hypotheses, the method outlined below that we used in our Spring 2019 courses would not change very much, except that the professor does not have to lead them to a particular hypothesis. However, the professor still must challenge the students' logic when brainstorming new hypotheses in order to arrive at a coherent and feasible hypothesis to test. Direct learning would maximally develop all of the research-relevant and transversal skills defined above, and could serve as a reference of reflection for future post-task activities.

## Hypotheses

Hypotheses for the study were determined beforehand:

- Hypothesis 1: Vowel space density
  *English will exhibit less V-to-V coarticulation than Spanish.*
- Hypothesis 2: Restrictions on onset/codas hypothesis
  *Codas are more restricted than onsets in Spanish, thus we expect to see less V-to-V coarticulation across VC#V in Spanish and more in English (see Mok).*
- Hypothesis 3: Segmental influence
  *The closer the degree of articulation of the consonant, the less coarticulation for both English and Spanish.*
- Hypothesis 4: Quantity of intervening consonants
  *Number of consonants intervening: coarticulation should decrease as quantity of segments intervening between V and V increases.*

We note that the inclusion of four hypotheses was deemed to be too much, and that in the future we would not be quite so ambitious.

## Description of task

Hypotheses were defined before the course started. The students come to class having read the pertinent bibliography. The professor uses guided discussion questions to get the students to arrive at the defined hypotheses. Start with basic definition of 'hypothesis' and drive conversation from there using Socratic dialogue (question/answer) method:

- What is a hypothesis, and what do we use them for?
- What is the difference between a hypothesis and research question?
- What do hypotheses reference? (answer: quantifiable variable)
- What hypotheses were presented in the papers you read regarding vowel-to-vowel coarticulation?
- What quantifiable variables did the researchers use to address their hypotheses?
- How does defining their hypotheses the way they did affect their methodology for the study?
- Consider the VCV sequence. What are the kinds of things that we could manipulate? (e.g., the type of consonant; the boundaries between elements of the sequence, such as VC.V vs. V.CV, etc.)
- Brainstorm of some ways that we could apply the hypotheses from the former studies to Spanish, or in the case of Fernández-Planas' study on V-to-V coarticulation, how could we further develop her hypotheses to test new questions for Spanish?

This is not an exhaustive list of the questions used in our course, they are merely good springboards to motivate conversation on the topic and arrive at an answer that looks something like the predefined hypotheses. It is not important that the students repeat exactly the predefined hypotheses, the professor, through rephrasing the student's hypotheses can 'put words in the students' mouths' so to speak. That said, we were pleased to find our

students were able to arrive at the hypotheses that we had come up with by the end of this activity.

## Examples of resources (non-exhaustive)

### Some of the readings distributed to our students were:

Fernández-Planas, A. (2000). Estudio electropalatográfico de la coarticulación vocálica en estructuras VCV en castellano. PhD dissertation, Universitat de Barcelona.

Mok, P. (2012) Effects of consonant cluster syllabification on vowel-to-vowel coarticulation in English. *Speech Communication,* 54: 946–956.

Mok, P. (2010) Language-specific realizations of syllable structure and vowel-to-vowel coarticulation. *Journal of the Acoustical Society of America*, 128: 1346–1356.

Ohman, S. (1966) Coarticulation in VCV Utterances: Spectrographic Measurements. *Journal of the Acoustical Society of America*, 39: 151–168

# LESSON: CORPUS CREATION

## Learning objectives/skill development

- Understand hypothesis sufficiently in order to create corpus
- Consolidate background (linguistic, phonological, phonetic) knowledge so that corpus is sufficiently controlled
- Relate measures to corpus items
- Attention to detail
- Organization

## Mode of delivery

**Blackbox:** The corpus creation may be blackboxed in the event that the professor does not deem it necessary to address the research-relevant and transversal skills outlined for this activity. The research-relevant skills may be addressed theoretically in class and the transversal skills could be acquired by performing other simulated or full engagement activities throughout the course of the project.

**Simulation:** For our Spring 2019 courses we simulated this exercise in order to maximally control the class project and plan the semester ahead of time, which would not have been possible if the students invented their own corpora. The benefit of simulating the project is that all research-relevant and transversal skills are worked, while permitting the professor maximum control over the projects direction and focus. Below we describe the method we used to simulate this activity for our Spring 2019 courses.

**Full engagement:** Full engagement may be desirable if the objective of the professor is to maximally work the research-relevant and transversal skills outlined above. The main benefit of full engagement over simulation for this activity is that the students have more control over the direction and focus of their research project, which may lead to optimal engagement by the students. This may be desirable with older students, especially those students who have had class with the professor before (or in sequenced courses, where learning objectives can be planned over two or more semesters). We have provided this as an option for the Spring 2021 implementation, as discussed in the paper.

## Description of task

This activity unfolds much in the same way the hypotheses generation activity was performed. The corpora (for English and Spanish) were already created by the professors ahead of time. In class, the students were first presented with the hypotheses they had formalized in a previous class (note: this is a good time to reformulate the wording of any hypotheses that were not exactly what the professor had defined beforehand). Then they were asked to assess the

corpora used in the studies in the bibliography. Each group was then asked to write a corpus for each hypothesis and define their reasoning in using those words. The professor mentioned informally that nonsense words may be considered, but that there may be lexical frequency effects to consider if nonsense words are used. This was mentioned informally in our sessions, since our corpus was already defined, but may need to be addressed in a more formal manner if this is used as a full engagement activity. Finally, the professor reveals the predesigned corpus to the class and he/she explains each part of the corpus and the rationale behind including those particular words, followed by an ample question and answer session.

## Examples of resources

- Sample corpora from previous studies for students
- Discussion of corpora provided in literature that was read

# LESSON: DATA COLLECTION

## Learning objectives/skill development

- Use of instruments – proper care of instruments – adhering to lab procedures
- Interaction with human subjects – following IRB protocols
- Testing experimental setup (e.g., sound levels)
- Professional interaction with people
- Collaboration with other experimenters (shared materials and space)
- Time management

## Mode of delivery

**Blackbox:** Blackboxing data collection may be especially suited for larger classes, or where lab time and space may be very limited. For large classes, the professor could simply divide pre-collected data, which the students will engage with. In this way, the students are still engaged with data, they simply do not have to go through the process of collecting it themselves. The research-relevant skills may be addressed theoretically in class, while the professor could plan to address the transversal skills in another activity.

**Simulation:** Simulating this activity as well may be best suited for large classes or where lab time and space may be limited. In a simulated activity, a few subjects may be recorded reading only part of the corpus, then the professor would supply the rest of the data with pre-recorded samples. This way, the research-relevant skills would still be addressed in an experience-based paradigm, though not all of the students would get hands-on experience with all skills. However, a simulated activity would still be more experience-based than simply addressing the research-relevant skills theoretically in class. The benefit to both the blackboxing method and the simulated learning method is that much time is saved in not having to collect all the data for the research project.

**Full engagement:** Full engagement may be desirable if the objective of the professor is to maximally work the research-relevant and transversal skills outlined above, which was the objective for our Spring 2019 courses. The main benefit of direct learning for this activity is that the students are maximally engaged in the data collection process, which empowers them to perform future research. Data collection is one of the bigger hurdles in any research project, and many students feel apprehensive about using recording equipment for fear they may do something wrong (or break something). For our Spring 2019 course, we wanted the students to get over this hurdle as fast as possible, which is why we immersed them directly in the data collection process as outlined below.

## Description of task (ultrasound imaging data)

The specific data collection procedures differed for each class due to the fact that different types of data were used. For the class at UNAV, ultrasound imaging data showing a midsagittal view of the tongue were collected. The students were the subjects for the corpus collected. Data was collected the second week of class before the project was introduced. The corpus was randomized and the tokens were inserted into carrier phrases in order to avoid detection of the target gestures being tested by the students. The students were informed that the objective of the task was for them to learn how to collect data for a project they would be doing in the future.

Students first read a self-elaborated tutorial about the ultrasound program and were given an introduction to ultrasound data and the required equipment in class (in the lab). Students were given time to 'play' with the ultrasound machine before data were collected. Data were collected outside of class time with the professor present, but only intervening to remind the students of the guidelines in the event that some guideline was being infringed upon.

## Description of task (acoustic data)

Students were required to recruit two participants each, either from friend groups, or by making an announcement in one of their classes (in accordance with IRB protocols). They then scheduled time in the lab to record their participants. Prior to recording, the class rehearsed going through the protocols, and each student had to schedule an in-person ``quiz'' with the professor to ensure that they knew how to position the microphone and test recording levels.

## Examples of resources

- Praat/Audacity
- Articulate Assistant Advance (ultrasound)
- Recording device / booth
- Video tutorials / live demos
- Written tutorials with illustrations

# LESSON: DATA SEGMENTATION

## Learning objectives/skill development

- Determining consistent criteria for segmentation and exclusion of tokens
- Application of knowledge re: acoustic correlates of segments
- Operation of software (e.g., PRAAT, Articulate Assistant Advanced©)
- Time management
- Attention to detail
- Decision-making
- Keeping detailed records (e.g., re: excluded tokens)

## Mode of delivery

**Blackbox:** Blackboxing data segmentation may be especially suited for classes with advanced students who are well familiar with data segmentation. In that case, it may be desirable to black-box data segmentation, which is time consuming, in order to focus on more complicated tasks such as advanced statistical analysis and scripting in R.

**Simulation:** Simulating data segmentation would be ideal if reusing previously collected data that are already satisfactorily segmented and time is limited. Under these conditions, it may be beneficial to simply walk the students through the segmentation procedure and criteria and give them a small sample set of the data to segment for homework and hand in by the next class, in which the segmentation task will be evaluated in groups and by the professor for a homework grade. In this way the research-relevant and transversal skills are addressed, though the students will not gain the level of expertise they would normally gain with the highly repetitive task of segmenting a large corpus.

**Full engagement:** Full engagement may be desirable if the objective of the professor is to maximally address the research-relevant and transversal skills outlined above, which was the objective for our Spring 2019 courses. The principal advantage of direct learning is that the students engage with a large data set in which many 'problems' are bound to arise. It is our belief that learning occurs when students are obliged to address real-world problems that arise, such as poor data quality, the target sound is missed or unclear and/or the signal is distorted. It is through resolving these predicaments (in groups and with the professor) that the students begin to hone their own criteria for data analysis, which they will use for future research projects.

## Description of task (ultrasound imaging data)

Students are directed to read the in-house tutorial on data segmentation before coming to class and watch the software's (AAA) video tutorial on YouTube. The students are given an

overview of the data segmentation process before the professor segments a few vowels while the students observe and ask questions. Each student is required to segment a set number of tokens and will be evaluated on the completion of the segmentation, as well as the accuracy. Segmentation must take place at the lab because the software only works with a specific USB key that is very expensive. Thus, students must schedule time at the lab in order to perform the assignment. The advantage is that the professor has the schedule so that they can be present during segmentation for the first week should problems arise.

## Description of task (acoustic data)

A special tutorial was held to go over the segmentation criteria for hand-labelling of TextGrids in Praat. Each student had to segment the data of both of the speakers that they recruited and recorded. Over the following two weeks, students were encouraged to ask questions. Students had to write a (rough) methodology section that explained how they determined segment boundaries as they went along; this ensured that students were explicit about their segmentation choices, and meant that they cleared them with their peers and the professor as they were working on it.

## Examples of resources

- Praat
- Articulate Assistant Advance
- Text editor
- Video tutorials / live demo
- Written tutorials with illustrations

# LESSON: DATA ANALYSIS (MEASUREMENT)

## Learning objectives/skill development

- Determine how to operationalize measurement procedure (e.g., window type/size)
- Write/modify scripts for extracting relevant measures
- Operationalization of measure extraction (i.e., writing code)
- Writing/modifying code (independent of actual language)

## Mode of delivery

**Blackbox:** Blackboxing data measurement extraction may be especially suited for students with limited knowledge of scripting/writing code. Blackboxing in this case allows the students to still perform the research, and still see that there is a measurement step involved in carrying out the research. For many students, it may be the first time they will have seen a script/code language, so even blackboxing this activity can provide a vast amount of information to the student.

**Simulation:** Simulating data measurement extraction would be ideal for upper-level students who have performed this type of task before or for students with a high skill level in technical tasks involving scripting. Simulating the activity ensures that all the research-relevant and transversal skills are worked, but that, should a problem arise and the students are not able to work out all of the technical kinks, they will still be able to perform the research.

**Full engagement:** Full engagement may be desirable if the students have performed research before, but lack the knowledge and skills necessary for data measurement extraction. In this case, the teacher could walk them through what a script is and how it works, as well as address program-specific syntax. This is probably an activity where an in-house tutorial would be advisable, as well as a 'recipe book' for script commands. It is worth noting that if this activity is performed via direct learning, the research project itself should probably be less 'complex' than it might otherwise be, for the simple fact that the more variables one is measuring, the more room for error there is and consequently frustration on behalf of the students.

## Description of task (ultrasound imaging data)

Data measurement extraction is quite simple due to the Articulate Assistant Advanced software. Segmented data are exported to the 'Spline Workshop' (a separate part of the same AAA software) where data analysis takes place. There individual measurements as well as means and standard deviations for the fan line that intersects with the tongue spline. Distance in mm from the center of the ultrasound probe for each of the forty-two fan lines is generated automatically for a chosen spline. This process is automated by a simple function that is

integrated into the software. In order to perform a statistical analysis for two groups of tongue splines, an automatic t-test function is also integrated directly into the AAA program, which generates t- and p-values for every one of the forty-two lines that the splines intersect. Because of this, the user can observe where in the tongue region the two groups diverge.

## Description of task (acoustic data)

Once data were segmented, students were provided with Praat scripts to extract the formant measures. Prior to this, and as an extension of the hypothesis generation activity, students did an in-class activity with their group members that had them operationalize the hypotheses in terms of specific variables, in this case, formants. Once students had the results in csv form, they were provided with R scripts to plot the data and look for outliers; these were sometimes the result of segmentation errors, which the students had to fix, or they were due to errors in the formant tracking software. These activities were done in so that the professor could be on hand to assist with decision making and any problems that arose.

## Examples of resources

- Praat
- Articulate Assistant Advance
- Text editor
- Video tutorials / live demo
- Written tutorials with illustrations

# LESSON: STATISTICAL ANALYSIS

## Learning objectives/skill development

- Understand relevant statistical tests for hypothesis/measures
- Importance of experimental design in drawing conclusions
- General scientific literacy:
  - Understanding of role of statistics in scientific inquiry (e.g., "rejecting the null")
  - Importance of experimental design in drawing conclusions

## Mode of delivery

**Blackbox:** Blackboxing the statistical analysis is ideal for beginning level classes where the students do not have the basic concepts of statistics. It is our belief that students can and should perform research even though they may lack some of the research-relevant skills. To blackbox this activity, it is necessary to have an R script (or other statistical software) handy and functioning to provide to the students. It is also necessary to teach them how to structure their data in Excel so that the R can read their data. The benefit to blackboxing is that the students learn about empirical methods, but do not become frustrated early because they lack the basic skills required for statistical analyses. We believe that a good experience with a blackboxed activity will make the students more confident for future research and motivate them to learn more about statistical analyses.

**Simulation:** Simulating data statistical analysis is best for classes where the students have some knowledge of statistics and scripting, but still need a crutch. Simulating would involve going through all the steps of the statistical analysis and script writing process and design activities in which the students create their own data analysis scripts. It would even be interesting to give the students different options such as t-tests, ANOVA and chi-square models and let them choose the statistical method they want to use and justify why they chose that particular method in a separate writing assignment. The students will use the script provided by the professor for the research project, but the students will gain the research-relevant and transversal skills by performing the simulation.

**Full Engagement:** Full engagement may be desirable if the students have performed research before and feel comfortable working independently on scripts. For full engagement, it would be good to choose a research topic in which a more advanced statistical model is justified in order to extend the students' knowledge beyond simple t-tests and ANOVA. Ideally, the professor should provide the students with in-house tutorials for any new statistical method and R packages, and follow up by evaluating the process by grading scripts and providing feedback to the students.

## Description of task (ultrasound imaging data)

For Spring of 2019, statistical analysis for the ultrasound data was performed using full engagement due to the fact that the AAA program has an integrated Student t-test function. First the professor provided the students with the theoretical scaffolding necessary to identify why t-tests are justified and how they work. Once the students performed exercises with t-tests, they were taught how to use the integrated t-test function in AAA and how to select pairs for analysis. The students performed the analyses individually and saved all the results which they turned into the professor for evaluation and verification. The good part about the AAA software is that since all the data were analyzed and saved on the lab computers. any anomalies in the results could be verified by the professor.

## Description of task (acoustic data)

In Spring 2019, the statistical analysis of the acoustic data was done using blackboxing, due to the fact that mixed models were used in the analysis. A high-level lecture on mixed models was given, and students were given scripts to run, which included scripts to plot interaction. These plots were then compared against schematic plots that the students had devised. Because proper implementation of mixed models requires model checking (which the students did not do), this part of the research would need to be redone before write up and submission of the study. Nonetheless, this approach allowed students to compare their hypothesized interaction effects with the interaction plots generated by the R scripts.

## Examples of resources

- Excel
- R/SPSS/MATLAB/Python
- AAA
- Video tutorials / live demonstrations
- Written tutorials with illustrations
- Recipe book of commands/sample codes for previous data sets

# LESSON: WRITE-UP/PRESENTATION OF RESULTS

## Learning objectives/skill development

- Interpretation of data
- Articulation of how results relate to hypothesis and measures
- Creation of appropriate tables, graphs, and figures to convey information
- Presentation of technical material
- Expositional writing

## Mode of delivery

**Blackbox:** Blackboxing the write-up/presentation of the results would be ideal if the professor is mainly only interested in the students' acquisition of the statistical skills involved in research. For example, if the professor were using the course to train new members to work in their lab, they may be more interested in that the students engage more with other research-relevant skills. In this case, a simple exposition of the groups' ground-level results via PowerPoint in which the professor provided a template with all the required information would suffice.

**Simulation:** A simulated exercise for data write-up/presentation may involve going through all the steps of results interpretation and providing the students with the scripts to make graphs. In this case, the students have the opportunity to interpret their data and make relevant tables/graphs and figures, but they would use scripts and resources the professor provides, and they may not present a final, polished product (only parts of a full write-up).

**Full engagement:** Student presentations are a common feature of semester-length projects, and so full engagement would be the default option. Beyond a traditional end-of-semester presentation, the professor may set the objective of publishing the write-ups in a student journal, or if the final presentation is a poster, to present their results at a student conference. If this is the objective, the professor should schedule the activities such that there is sufficient time to polish the final products at the end of the semester in order to provide workshops and seminars on academic writing. It would be advisable to take advantage of any university services that provide support in the way of writing centers or seminars on academic writing (available at many universities).

## Description of task (ultrasound imaging data)

For Spring 2019, results presentation was delivered by full engagement. The final presentation was a scientific poster that each group had to create for their hypothesis. The final month (once results were becoming more clear) the professor asked the students to give weekly oral presentations of their ongoing results. Presentations were informal and colloquial style.

Students were challenged by the professor and the class during this process. The final two weeks, the students were given two different seminars on writing up results in a succinct manner that is appropriate for a scientific poster. A template of a poster was also provided in which the students simply needed to follow the structure, but were told to deviate from it if the need arose. The final posters were presented via video conference to [AUTHOR 1]'s class at [INSTITUTION 1], where her students had the opportunity to challenge the [INSTITUTION 2] students and ask questions. In past years, special poster sessions have been held in which professors from the department were invited to attend and ask the groups questions about the research projects. The professors' evaluations of each group were taken into account for the final grade.

## Description of task (acoustic data)

Each group wrote a single paper for submission, and as writing was happening while the last stages of data analysis were happening as well, students were encouraged to take ownership of different parts of the final stages of the project. This required a lot of collaboration on the part of students: for example, if one student was writing the methodology section, they had to confer with their group members about what, precisely, was done at each stage. Students created PowerPoint presentations to present the results of their data, which they did at a videoconference at the end of the term to [AUTHOR 2] and the students at [Institution 2].

## Examples of resources

- Copy of appropriate style guide
- Sample papers
- Paper/poster templates
- Academic writing seminars/workshops