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Investigating Statistical Learning of Nonadjacent Dependencies: Running Statistical Learning Tasks in Non-WEIRD Populations

Contributors: Rebecca L. A. Frost & Marisa Casillas
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Abstract

Language acquisition is complex. However, one thing that has been suggested to help learning is the way that information is distributed throughout language; co-occurrences among particular items (e.g., syllables and words) have been shown to help learners discover the words that a language contains and figure out how those words are used. Humans' ability to draw on this information—"statistical learning"—has been demonstrated across a broad range of studies. However, evidence from non-WEIRD (Western, Educated, Industrialized, Rich, and Democratic) societies is critically lacking, which limits theorizing on the universality of this skill. We extended work on statistical language learning to a new, non-WEIRD linguistic population: speakers of Yélî Dnye, who live on a remote island off mainland Papua New Guinea (Rossel Island). We performed a replication of an existing statistical learning study, training adults on an artificial language with statistically defined words, then examining what they had learnt using a two-alternative forced-choice test. Crucially, we implemented several key amendments to the original study to ensure the replication was suitable for remote field-site testing with speakers of Yélî Dnye. We made critical changes to the stimuli and materials (to test speakers of Yélî Dnye, rather than English), the instructions (we re-worked these significantly, and added practice tasks to optimize participants' understanding), and the study format (shifting from a lab-based to a portable tablet-based setup). We discuss the requirement for acute sensitivity to linguistic, cultural, and environmental factors when adapting studies to test new populations.

Learning Outcomes

By the end of this case, students should be able to

- Define statistical learning and describe how it can be examined in the laboratory
- Understand how the experiment we conducted on Rossel Island was designed to test statistical learning in adults
- Consider how different testing options may be sensitive to the linguistic and cultural backgrounds of target populations.

Project Description and Context

Background

Human language is highly complex, and learning a language is held to be one of the most complicated feats in human learning. Yet, we do so with remarkable ease. Establishing exactly how we can do this so readily is a mainstay of psycholinguistic and cognitive science research. One thing that is suggested to help with language learning is humans' predisposition to detect patterns; children and adults alike are highly sensitive to patterns in the world around them, including the patterns that exist in the language they are trying to learn. Upon close inspection, we can see that the world's languages are full of patterns and regularities that can

assist learning. For instance, the way in which particular syllables co-occur can help learners to figure out which ones come together to form words, and patterns in the way those words are used can help learners to discover how a language operates in terms of its grammatical structure. Research suggests that there are particular cognitive mechanisms that serve to detect, store, and generalize these patterns, through a process known as “statistical learning.” In this study, we extended work on statistical language learning to test a new linguistic population: speakers of Yélî Dnye, located on Rossel Island, Papua New Guinea.

Project Overview

We focus our investigation on statistical learning of nonadjacent dependencies—a special feature of human language that can be acquired through statistical learning. A nonadjacent dependency is a relationship between two things that are separated by intervening material (thus, the related parts are nonadjacent). These types of relationships are pervasive in language and exist at multiple levels of language structure, including syntax (i.e., the relationship between “is” and “-ing,” for example, is laughing, is singing), morphosyntax (i.e., co-occurring prefixes and suffixes, for example, uncovered, independently), and number agreement (i.e., the child at the park plays, the dogs at the park run). By investigating the process by which human minds learn nonadjacent dependencies, we can come one step closer to understanding how language acquisition unfolds.

Many researchers have examined statistical language learning in adults and children and have found evidence that nonadjacent dependencies can be learned after very little exposure. For example, Erika Marchetto and Luca Bonatti (2013) found that children as young as 12 months old could detect nonadjacent dependencies in speech after hearing them for just 2–3 min.

In a study with adults, Rebecca Frost and Padraic Monaghan (2016) trained participants on a new language that contained some novel words, each of which contained a nonadjacent dependency. Participants heard these words for 10 min, and words were presented in a random order in a continuous stream of speech (i.e., with no pauses between words). The words contained a nonadjacent relationship between the first and last syllable, such that particular syllables always appeared together, regardless of what came in between (e.g., ba-x-du; ba and du would always appear together, no matter which syllable intervened between them). Importantly, the only way that learners could discover the words and the rule-like structures they contained was through statistical learning, that is, by computing over the patterns of syllable co-occurrence.

To assess learning, Rebecca Frost and Padraic Monaghan (2016) presented participants with a two-alternative forced-choice test, which comprised pairs of words that were either familiar (based on the language they had just heard) or unfamiliar. For each pair, participants had to pick which word seemed to fit the language best. They tested segmentation with word pairs that contained word versus part-word comparisons, with words being taken directly from the language, and part-words comprising the end of one word, and the start of another. If participants had segmented the words from speech, then they would select the words over the part-words on this task. Nonadjacent dependency rule learning was tested in the same way, using comparisons that contained part words (which were the same as before) and rule words,

which contained the trained dependencies, but with a new intervening item. If participants had learnt the dependencies, then they would select rule words over part words.

Learners succeeded on both of these tasks and were equally good at identifying words and identifying the within-word nonadjacent dependencies. These findings are important because, contrary to prior suggestions, they show that learners may be able to use the same statistical information to identify complex morphological structure at the very same time that they are trying to learn what the words in the language actually are. Rebecca Frost and colleagues (2020) have recently found similar results for infants, adding further support to this possibility.

Although statistical language learning theories should, in principle, apply to all human populations, they have been almost exclusively developed and tested using a very small slice of humanity. That is, participants in past statistical language learning research have usually come from developed, educated, and monolingual sub-communities within Western societies, with many studies testing undergraduate students (i.e., 18–23 year olds), thereby limiting the participant samples even further. If current theories surrounding statistical learning are correct, researchers should be able to replicate established experimental findings in any other human population.

Aims and Hypotheses

Our goal in this study was to investigate nonadjacent dependency learning in a very different population than has previously been tested. We attempted to replicate the work by Rebecca Frost and Padraic Monaghan (2016) with adult participants from a small-scale, traditional subsistence farming community in remote Papua New Guinea—speakers of Yélî Dnye, living on Rossel Island. We predicted that we would replicate the previous findings following some adaptations to the instructions (to make these more appropriate to the cultural context of the testing site). Ultimately, however, we found that the task requirements did not adapt easily enough for cross-cultural research, and we were therefore unable to replicate the original findings. In what follows we describe our method and findings and then discuss fruitful alternative approaches for future work along these lines.

Section Summary

- Language is replete with statistical information, and learners of all ages have been found to be capable of drawing upon this information to aid their learning—including learning of nonadjacent dependencies.
- Although evidence for this ability is plentiful, it largely comes from a small pocket of the world's language users, mostly Western populations (and typically University undergraduates).
- The aim of the study described here was to extend research in this field by testing statistical learning of nonadjacent dependencies for the first time in a remote community in Papua New Guinea, with speakers of Yélî Dnye.

Research Design

Our study was designed as a replication of Rebecca Frost and Padraic Monaghan's (2016) experiment, save for a few necessary adjustments in light of the situational and linguistic differences between this new study and its predecessor. We maintained the key methodological features of the original study, in so far as participants were trained in a new language composed of novel words, each of which contained a nonadjacent dependency. Participants heard these words for ~15 min, and words were presented in a random order in continuous speech (i.e., with no pauses between words). Note that although the exposure phase was longer here than in the original study, the actual *amount* of exposure was the same (each word was presented the same number of times in both studies, but the duration of individual words here was very slightly longer). As before, the words contained a nonadjacent relationship between the first and last syllable, such that particular syllables always appeared together, regardless of what came in between. As in the original study, the only way that learners could discover the words and the rule-like structures they contained was through statistical learning, that is, by computing over the patterns of syllable co-occurrence. After the exposure phase, participants completed a two-alternative forced-choice test, comprising pairs of words that were either familiar (based on the language they had just heard) or unfamiliar. For each pair, participants had to pick which word seemed to fit the language best. This test examined segmentation and generalization, in line with the original study.

The first adjustment was that we ran the study on a tablet computer in a quiet area of someone's house, rather than on a desktop computer in a laboratory testing booth. This was necessary as there is no electricity grid on Rossel Island, and there are no quiet testing rooms to use. Tablet computers allowed us to run the experiment with solar power, and enabled us to easily conduct testing across the island, in any given household in the community.

The second adjustment was that we paired videos of animals with the auditory sound file that was played during training, so that participants had something to watch while they were being familiarized with the artificial language. The addition of these animal videos increased participants' engagement with the tablet and helped to focus their attention on the task. This change was helpful as we could not fully control other sights and sounds around the testing areas; we knew that the circumstances within which participants completed the study on Rossel Island were likely to be far busier than those experienced by participants in the original laboratory-based experiment.

The third adjustment was that the artificial language was amended so that it was suitable for testing speakers of Yélî Dnye (rather than speakers of English, as in the original study). We made sure that all of the phonemes and syllables contained within the artificial language were either native to Yélî Dnye or were frequently used in borrowed words. This adjustment ensured that participants could easily distinguish between all of the individual sounds used in our stimuli, which is crucial for conducting a fair assessment of learning.

Finally, we also modified the instructions quite substantially and incorporated a more thorough overview of the task requirements as well as a practice test (details given below), to try to ensure that the nature of the

task was fully understood by each participant.

In sum, while the structure of the main experiment was nearly identical to that reported by Rebecca Frost and Padraic Monaghan (2016), the instructions, linguistic material, and style of presentation were adapted for testing on Rossel Island. The methods and preparatory research practicalities are described in more detail below.

Section Summary

- The study was designed as a conceptual replication of Rebecca Frost and Padraic Monaghan (2016), which trained participants on an artificial language for ~15 min, and tested learning using a two-alternative forced-choice task.
- We made some necessary adjustments to accommodate the unique situational requirements of testing on Rossel Island and to account for the linguistic differences between the current and prior sample.
- We adapted the presentation to a tablet rather than desktop design and modified the linguistic input to contain sounds taken from Yélî Dnye, rather than English. We also paired the auditory input with some visual scenes, to help keep participants' attention, and we added a training phase to make sure the task requirements were clear (to listen to a sound file and then to pick which one of two test items best fits with that sound file).

Research Practicalities

Preparation for Fieldwork

Before testing could begin—indeed before we could make a research visit to the island—we first applied to our local institutional committee for ethical approval and to the authorities in Papua New Guinea for scientific research visas. This process took over a year in total and cost several hundred euro per team member. Researchers wishing to conduct similar work must plan ahead in advance for getting proper approval through both their home institutions and the nation/region where testing will take place.

In this case, we knew that testing would likely be permitted by island leadership given our existing relationship with the community. Those who are visiting a community for the first time must also factor in time and resources for developing these relationships. Endorsement by local community leaders is essential for recruiting participants and getting access to adequate testing areas. Community leaders can also advise researchers in deciding what kind and quantity of compensation to give to participants, such that compensation will be considered fair but won't disrupt the workings of the local economy. Preparation for this trip also required us to estimate the amount of electrical power needed to set up and run the study on-site (e.g., multiple large solar panels and a locally purchased truck battery for reserve computing power), along with sourcing the other items needed for testing and living on Rossel Island over the course of the field trip (e.g., bedding, malaria pills).

When the researcher is not a native member of the community under study, as in our case, the cultural perspective, social skills, and linguistic access of someone local to the community are invaluable for ensuring that experiment development, participant consent, and testing are conducted as well as possible. For this study, we worked with two local research assistants, born and raised on the island.

Methodological Practicalities

We started by training the research assistants—partly by asking them to complete the experiment as pilot participants. These initial runs indicated that the minimal instructions used by Rebecca Frost and Padraic Monaghan (2016) were insufficient to communicate the requirements of the task in this context. For example, the original instructions rely on the participants deciding which of the two sounds in each test pair is "more" like the sounds they heard during training (in line with research in this domain). But in Yélî Dnye, there is no word for "more," nor are there any other comparative phrases, such as "better." To make the instructions more suitable for speakers of Yélî Dnye, the experimenter and the local research assistants worked together to make incremental changes to the wording. This new wording was tested with further pilot participants.

During these pilot runs, it became clear that we needed to assess participants' understanding of the instructions to ensure adequate completion of the study. Thus, we created a practice task to append to the start of the experimental session, which tested comprehension of the instructions (described in more detail below). The experimenter and the local research assistants worked together to design and test this practice task, adding components to familiarize participants with the concept of listening to audio files and selecting one of two clips in a two-alternative forced-choice format. Importantly, the stimuli used for this practice task were non-linguistic (instead, we used short music clips), so as to not interfere with the primary task. This practice task was then integrated into the study along with the updated instructions. The same research assistants also helped create a translation of the crucial concepts for informed consent so that we could properly inform each participant about their rights during testing (e.g., their right to withdraw).

We had approximately 2 weeks to test nearly 60 native Yélî Dnye speakers (final $N = 57$) within a limited age range. To maximize efficiency of data collection, we rehearsed the instructions many times, manually prepared paperwork to collect demographic information from each participant, and made a checklist of items to prepare and pack for mobile testing. Then, we recruited participants and conducted the experiment at three locations around the island, casting as wide a net as possible in the local community (some participants walked ~1 hr to arrive at the local experiment site).

Section Summary

- To conduct field work, there are a number of important preparatory steps which must be completed, including acquiring ethical approval, and obtaining permission from all relevant bodies (including from the local community), as well as ensuring you have the necessary means to live and work in your desired study location.
- When the researcher is a visitor to the community, the help of a community member and community

leaders is indispensable for ensuring that the study is done soundly and ethically.

- After pilot testing, we had to implement a number of changes to the study to make it suitable for testing our intended sample. Most of these changes were made to accommodate the linguistic differences between our new sample and the one in the original study, which meant the instructions for our original task were difficult to interpret.

Method in Action

Once we had recruited some participants and identified a quiet, relatively distraction-free testing area, we set up the tablet, headphones, notebooks, and compensatory gifts for participants in advance of the first participant's arrival. When each participant entered the testing area, they were first taken through informed consent and then asked about some basic demographic information (e.g., age, languages spoken, years of school completed, village where they live). Because the island population is very small, sometimes the research assistant already knew the full demographic information and had no need to verify it with the participant. In these cases, the research assistant communicated this information to the experimenter while the participant listened to the artificial language.

After we had collected informed consent, the instruction phase began. At the start of the instruction phase, the participant, the research assistant, and the experimenter all donned headphones. The research assistant played an unrelated audio sound file (a recording of someone reading a book) and increased the volume until the participant indicated that they could hear it clearly and comfortably. Then participants were told that they would watch some videos, some short and one long, and that they would answer questions after each video. Next the research assistant began the instructions and practice phase by telling the participant that they were about to see a short video and to simply listen and try to remember what they heard. The research assistant informed participants that the visual images in the videos were only there to look at during listening and weren't important to remember. The short video contained these images (short video clips of animals and nature scenes, obtained from https://coverr.co/tags/animals) plus auditory sequences of three consecutive pure tones, all rising in pitch, with these three-tone sequences separated by a short silence.

Once the short video was over, the research assistant explained to the participant that this is the type of video that they would watch in the experiment and that they would see it again in a moment. Then, the assistant explained that next time, when the video ended, it would be followed by two sounds, one of which is "good" for the types of sounds heard in the video and one that is "not good," and that their task was to remember what they heard in the video and to tell us which of the two sounds was good for the video they saw (remember, there is no word like "better" or "more" in this language, so "good" was the best way to approximate this type of comparative question). Then, participants saw the short video again and were presented with three test trials in which they had to choose between pairs of sounds (rising and falling, or rising and flat), randomizing which sound played first for each pair. They chose between sounds by tapping a button labeled "1" or a button labeled "2" for the first and second sound they heard, respectively (the numbering was also explained in the instructions).

If participants chose the wrong sound in the practice trials (e.g., they chose the falling sound instead of the rising one), the research assistant and experimenter gave feedback to let the participant know they had selected the wrong answer. The experimenter and assistant then reviewed the instructions again and then re-played the training video again before asking participants to complete the practice trials once more. If participants managed to give at least two correct responses, they were shown a second practice video with a different short sequence of tones and were tested in a similar manner for understanding. If participants were unable to give at least two correct responses after 2–3 iterations of a practice video, we ended the experiment early, thanked participants for their time, and compensated them equally to participants who completed the whole task.

Participants who passed both practice videos continued with the main task. We would then play the video containing the artificial language (~15 min), following this with the test pairs, which examined word identification and nonadjacent dependency learning (presented in a randomized order). Participants were told that this final task was the same as the previous ones, only the video would be much longer and that the sounds came from a new language "Nâmuwâki" that sounds like Yélî Dnye, but is not Yélî Dnye (or any other language they might have heard) because we made it up and the words don't mean anything.

Despite all these adaptations, testing was challenging. We tried our best to collect data while sitting at a table inside, with the door and windows of the house closed to minimize distractions. However, on one day we had to test outside at a table under the eaves of a house; we sat with the participant facing the exterior wall of the house (this affected data collection for approximately eight participants). On another occasion, we tested in another village where we set up in someone's kitchen; because kitchen tables are not typically used on Rossel Island, we sat on the floor with the door and windows closed, yet numerous people were sitting outside the door and testing was interrupted several times, often by children trying to access their mothers who were participating (this affected data collection for approximately five participants).

It was also difficult to stick to precisely the same protocol for the practice sessions for all participants—with this difficulty laying in cases where it was uncertain how well we had communicated the concept of the task. For some participants, we had to alternate between the two practice videos to try to illustrate the nature of the task, and in some cases we ran up to 4–6 failed iterations of these. This tended to happen when participants appeared to understand the task in the first practice session, but then demonstrated otherwise in the second. Importantly though, despite this variation, participants were only allowed to continue to the main task if they first demonstrated task understanding by getting most trials correct in both videos 1 and 2. The entire session was intended to take about 30 min, but typically took around 40 min, sometimes up to 50. Participants were compensated with instant noodle packets—a shareable but sought-after commodity on this remote island. We tested $N = 57$ participants in total, aged between 16 and 35 years of age.

Study Outcome

Ultimately, we did not replicate the original findings by Rebecca Frost and Padraic Monaghan (2016): participants' choices were at chance level. We also found that participants often hesitated for a few seconds

before responding on many trials—indicating that they were reflecting quite heavily on their options, rather than making an instinctive choice.

Section Summary

- The experimenter and local research assistant worked collaboratively to recruit and test participants across Rossel Island, testing $N = 57$ in total.
- Although we made several adaptations to the study to make it suitable for field testing, we faced some unanticipated problems during data collection—particularly regarding communicating the requirements of the task and adhering to the same protocol for doing so for each participant.
- We made a number of further changes to the study "on the fly" to accommodate these issues. We had to be much more flexible and proactive than in typical laboratory studies to complete this study due to the constraints on both time and participants. This approach to research is essential when testing in remote locations due to the scarcity of such research opportunities.

Practical Lessons Learned

Adapting this statistical learning study for use in a non-industrial, non-Western population revealed important practical considerations regarding task selection for running statistical learning in different communities. These considerations chiefly relate to the experimental task that we used to investigate implicit language learning: As is often the case in this line of research, our task (a two-alternative forced-choice task) relied on metalinguistic responses (i.e., conscious reflection and speaking about language). While this task is highly capable of shedding light on participants' knowledge under the right circumstances, it is heavily reliant on core underlying concepts such as direct comparison of linguistic forms (e.g., considering if an item is "more"/"less" like something) and also on the types of behaviors that are expected in a formal and scholastic language setting (e.g., explicitly expressing a "correct" answer as a novice/learner to an apparent expert/experimenter). Because some of these concepts and behaviors were relatively unfamiliar in the population with which we conducted this study, this methodological choice led to extreme difficulties. Thus, the crucial practical lesson learned is to ensure task suitability and to consider this well in advance—even if this means deviating from the methodology of an original study and running a conceptual (rather than a true) replication.

Going forward, to more effectively study statistical learning across the world, researchers may benefit from using different methods, namely tasks that are more closely linked to natural everyday language use. For example, another way to measure participant learning is to have them occasionally repeat sequences of syllables in the artificial language. Prior work using this method has shown that the mistakes participants make reflect their current knowledge of the artificial language (e.g., Isbilen et al., 2018). Immediate repetition of speech is a natural mechanism for resolving misunderstanding in human interaction and has been documented across a diverse sample of the world's language communities (Dingemanse & Enfield, 2015; Dingemanse et al., 2018), therefore we would expect repetition to be easier to effectively leverage in experimentally testing learning compared to overt selection of one of a pair of words.

To conclude, the fewer words and adaptations needed for instruction, the more comparably the task can be conducted across sites. If we can find better ways to comparably conduct statistical learning experiments across diverse populations, we can better understand which aspects of these proposed learning mechanisms are truly universal to human cognition and which are crucially built up through the participant's prior experience with their language environment.

Section Summary

- Implicit statistical learning tasks often rely on metalinguistic judgment, often a comparative judgment, with participants selecting which item "fits best" with the trained language.
- Our adaptations tried to address this through careful rephrasing of instructions, and practice tasks, but our adaptations were not enough to enable successful replication.
- In future research, it may be advantageous to keep instructions minimal and instead use a task that does not include comparative judgments, for instance, a speech repetition task.

Conclusion

In this study, we attempted to replicate an experiment that was designed to test nonadjacent dependency learning in adults, which was conducted in laboratory settings, using a sample of highly educated Western adults (Frost & Monaghan, 2016). We amended the original experiment to test the same research question with a new population; a sample of subsistence farmers living on a remote island in Papua New Guinea. We did this with the view that similar results from this very different population would provide robust support for the universality of the proposed mechanisms underlying statistical learning. Although we made many adaptations to the instructions, and a few minor adaptations to the study itself (to make the method more suitable for testing in this population), we were unable to effectively replicate the original findings. However, the lack of comparative words such as "more" and "better" in the local language and the novelty of making metacognitive judgments in a two-alternative-forced choice context resulted in data that are difficult to interpret; it is unclear if participants did not show learning in this task because they did not learn or because the task was unsuitable.

Upon reflection, we determined that metalinguistic and metacognitive judgments of this sort may be problematic more generally for comparative studies of learning across different cultures and languages. We would recommend that researchers doing comparative work in the future select tasks that leverage everyday behaviors, passive reactions, or tasks that otherwise require little overt explanation.

Although we ultimately were unable to draw strong conclusions from this study, we found our replication attempt enlightening in that it revealed an implicit bias in how research studies are designed for highly educated Western populations and gave us the chance to see how effectively and flexibly we could adapt such a study in an entirely new and different context. We also note that the involvement of local research assistants was crucial to the success that we *did* have, and we will further develop these collaborations in future experiment adaptations.

Section Summary

- Local research assistants can provide critical insights during the study adaptation process; their expertise is often invaluable.
- Extending “tried-and-true” methods to new populations can shed important light on culture-specific design choices, and other methodological points of weakness, while inspiring experimental innovation. Tasks that require little instruction may be a key way forward for comparative experimental work.
- Ill-suited methods can result in uninterpretable results; in this case, we were unsure whether participants were unable to learn the nonadjacent dependencies in the input, or whether we simply failed to effectively communicate the task demands, despite our efforts. Future work with more suitable methods will help disentangle these possibilities.

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Classroom Discussion Questions

Classroom Discussion Questions

1. What are the challenges of running replication studies in a variety of populations?
2. What are some of the main practical challenges of running empirical studies in remote contexts?
3. What were some strengths and weaknesses of our approach to testing statistical learning in speakers of Yélî Dnye?
4. How would you do things differently if you were to conduct this study in a similar setting?

Further Reading

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Web Resources

More information on statistical learning, written for the public: http://www.lucid.ac.uk/news-events-blog/blogs/language-learning-by-numbers/

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