

REPORT DOCUMENTATION PAGE

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14. ABSTRACT This project investigated the neurocognitive basis of individual differences in complex skill acquisition, with the goal of bridging neuroscience and screening and training protocols. Our research is leading the field of neuropsychometrics, using electrophysiology and fMRI measures of brain functioning to decode information processing characteristics of individual brains and relate them to learning capabilities. We leveraged data obtained by affordable, consumer-grade neuroimaging technology to augment behavioral screening and placement tools and then used neurostimulation to augment learning.					
15. SUBJECT TERMS individual differences, complex skill learning, second language aptitude, neuropsychometrics					
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a. REPORT	b. ABSTRACT	c. THIS PAGE			Chantel S. Prat
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INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

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3. DATE COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

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5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33315-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report. e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

5f. WORK UNIT NUMBER. Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES). Enter the name and address of the organization(s) financially responsible for and monitoring the work.

10. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

11. SPONSOR/MONITOR'S REPORT NUMBER(S). Enter report number as assigned by the sponsoring/monitoring agency, if available, e.g. BRL-TR-829; -215.

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13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

16. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

17. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

Learning Complex Cognitive Skills: Bridging Neuroscience and Education through Individual Differences Research (N000141712607)

Final Report 06/01/17-05/15/20

Drs. Chantel Prat and Andrea Stocco

Department of Psychology & Institute for Learning and Brain Sciences
University of Washington

1. What were the major goals and objectives of this project?

The goal of our proposal was to investigate the neurocognitive basis of individual differences in complex skill acquisition, with the intention of bridging basic neuroscientific research with applications for screening and training military personnel. The vast individual differences that exist in the ability to acquire new information and to master complex skills must be rooted in varying information-processing capacities of individual brains. Thus, leveraging the field of cognitive neuroscience to understand the nature of individual differences in learning allows one to move beyond characterizing ability at the behavioral level, toward a more complete understanding of *why* an individual performs at the level he or she does. Such an understanding is critical for informing education and remediation attempts. Importantly, the availability of affordable, consumer-grade neuroimaging technology allows for the possibility of augmenting behavioral screening, placement, and assessment tools with the addition of accessible measures of neural functioning. With these tools, we have continued to define the field of **neuropsychometrics**, discovering neural measures of aptitude, and using them to better understand which minds and brains will excel under varying circumstances.

The overarching goal of the current proposal was to extend the neuropsychometric indicators developed based on previous funding to the point at which they could be used to create measurable improvements in screening and training techniques. To do so, four interrelated aims were addressed: (1) Describe the neural mechanisms that give rise to efficient second language learning, with an emphasis on understanding the extent to which they reflect static characteristics of brain structure versus a dynamic ability to get the brain ready to learn; (2) Specify the learning processes that link individual differences in resting state EEG (rsEEG) and rate of second language learning by examining the extent to which these indicators predict learning more broadly in domains such as computer programming, or more specifically, such as the acquisition of declarative versus procedural knowledge; (3) Relate individual differences in complex skill acquisition to different learning strategies; and (4) Bridge neuroscience and education by pairing our existing individual differences research with neuroengineering tools to improve second language learning by shaping neural circuits.

To achieve these goals, we applied experimental research involving complex skill training and computational modeling, iteratively. A central feature of the experimental work to date has been

the use of the Operational Language and Culture Training (OLCT) system (Johnson & Valente, 2008) developed by ONR research, to systematically expose participants to a second language using an immersive, virtual reality environment. Although the OLCT system provides a rich language experience, including tests of auditory comprehension and speech production, as well as the more traditional testing, the software we are using is no longer supported. As such, we began using Duolingo in our last experiment. Additionally, we extended this work by exploring individual differences in the ability to learn the Python programming language through the interactive online learning platform Codecademy, and compared the neurocognitive predictors measured to the previously identified predictors of natural language learning.

2. What was accomplished toward achieving these goals?

Aim 1: To uncover the neurobiological mechanisms that underpin the rsEEG predictors of complex skill learning, particularly in the beta frequencies

Over the period of funding, we collected usable multimodal neuroimaging data from 78 individuals. Each of these have resting-state fMRI (rsfMRI), eyes open and eyes closed rsEEG, and on task EEG, as well as structural brain scans. To better understand what the source(s) of individual differences in the frequency bands of interest are, we first correlated resting state beta power obtained from EEG with basal ganglia connectivity at rest. The results suggested that higher beta power was observed when individuals had greater connectivity in fronto-striatal loops, including connectivity between the caudate nuclei, the thalamus, the anterior cingulate cortex, the insula, and the inferior frontal gyrus (Prat, Zeitlin, Mottarella, Yamasaki & Madhyastha, 2019: Figure 1). This is consistent with an idea recently proposed by Miller, Lundqvist & Bastos (2018) suggesting that beta power operates like a gate to working memory and frontal representations, which has also been proposed to rely on basal ganglia functions.

The second set of analyses looked at the relation between beta power *during* learning (as opposed to at rest) and language learning aptitude. These analyses show power in the beta frequency bands over right temporo-parietal regions during learning was a significant predictor of learning outcomes including quiz and post-test accuracy ($ps < .005$). Differently from rEEG, however, power in the theta band and peak alpha frequency over the same regions predicted subsequent grammatical proficiency outcomes ($ps < .02$). Taken together, these data suggest that EEG obtained from learning data both replicate and extend our previous rEEG neuropsychometric measures.

Third, to see whether resting-state beta power predicted individual beta power during language learning, we correlated the two measures on a channel by channel basis. Power in the beta band at rest was significantly positively correlated with power in the beta bands during learning in all channels ($ps < .01$).

Fourth, to determine whether our findings in beta frequency bands, defined at the group level, were partially driven by fast alpha frequencies or high alpha power, we conducted a separate analysis in which beta bands were defined on an individual basis, centered on each individual's peak alpha frequency. Our results suggested that many of the resting-state beta effects were diminished by this adjustment. Consistent with the idea put forth by Miller et al. that "beta is the frontal lobe's alpha," these findings suggest that part of the predictive utility of beta

power previously measured is driven by fast or large alpha peaks which are detectable in canonical beta frequencies. Taken together, these findings suggest that the previously observed predictive utility of resting-state beta power reflects enhanced synchronization in a fronto-striatal network purported to function as a gating mechanism that allows task-relevant information to enter working memory. This mechanism, detectable at rest, is correlated with both brain and behavior during complex skill learning.

Aim 2: To specify the learning processes that link individual differences in resting state rsEEG and rate of second language learning by examining the extent to which these indicators predict learning more broadly in domains such as computer programming.

During the funding period we completed the first study investigating the neurocognitive predictors of learning to program in Python (Prat, Madhyastha, Mottarella & Kuo, 2020). The paper, which showed that predictors of natural language learning (including rsEEG) could predict up to 72% of the variance in learning programming languages (Figure 2 & 3), has been quite influential. Since its publication in March of 2020, it has been downloaded over 60,000 times, and is ranked 1st for impact on Scientific Reports. Since that time, we have begun comparing individual differences in the ability to learn programming languages to the ability to learn natural languages directly, in 19 participants who completed both Python and language training in the lab (in varied orders). Learning outcomes for both skills were highly correlated. For example, post-test vocabulary scores in French were strongly, positively correlated with programming accuracy in Python [Figure 4: $r(19) = 0.68, p = 0.008$]. We are currently writing up these results for publication.

Aim 3: To predict strategies for complex tasks from neurocognitive indices.

To advance our understanding of complex skill learning, in 2019 we began a series of computational modeling investigations of the role of declarative and procedural learning mechanisms in complex skill learning. We conducted a behavioral experiment in which 83 participants completed five psychometric tasks commonly used to assess individual differences in procedural learning (the Weather Prediction Task - Li et al., 2016, the Probabilistic Stimulus Selection task - Frank et al., 2004), working memory capacity (3-back updating task - Redick et al., 2013), or variability in the relative reliance on procedural versus declarative memory (Artificial Grammar Learning - McAndrews et al., 1985, and Stimulus Response Mapping - Collins et al., 2018). Our goal was to explore the possibility of using performance on some subset of these tasks to predict performance on the other tasks. Interestingly the bivariate correlations between tasks typically believed to measure the same thing were not significant. Instead, our results suggest an interaction between task demands and individual processing capabilities, suggesting that individuals will dynamically deploy declarative and procedural learning systems depending on particular task characteristics. We then took the stimulus response task and created three computational models in ACT-R which reflect differences in the strategies one might deploy to accomplish the tasks (Figure 5: reinforcement learning, declarative memory, or combined). In our paper entitled "One size doesn't fit all: Idiographic computational models reveal individual differences in learning and meta-learning strategies" (Haile, Prat, & Stocco, 2020), we showed that each of these models was the best fit for some

subset of participants, with the declarative learning model fitting the most participants (N=38), and the reinforcement learning model fitting the smallest number of participants (N=4), and each of the combined models falling in between (see Figure 6).

In FY 2019-2020 we also began exploring the neural correlates of declarative and procedural learning mechanisms. One study looked at rsEEG correlates with performance on the stimulus-response learning task. We found that power in rs beta bands was correlated with the rate of forgetting in the declarative (short) blocks, consistent with the idea that rs beta reflects individual differences in working memory gating. Our next steps will be comparing rsEEG in the groups of participants who were best fit by each model, and then correlating the learning parameters of those models with rsEEG.

Also in FY 2019-2020, we extended this research on learning strategies to investigate the relation between resting state fMRI (rsfMRI) and learning outcomes traditionally related to declarative (vocabulary) and procedural (grammar) learning systems. We found that correlations between hippocampus and fronto-parietal networks at rest uniquely predicted vocabulary learning, while connections between basal ganglia and default mode networks uniquely predicted grammar learning (see Figure 7). These findings are in the process of being written up for publication.

Aim 4: To bridge neuroscience and education by pairing individual differences research with neuroengineering to improve second language learning

From FY 2018 onward, we conducted a series of investigations using neurostimulation (transcranial direct current stimulation: tDCS) protocols to target two different circuits known to be related to declarative learning and procedural learning. In the first experiment, we ran 96 participants through an artificial grammar learning paradigm. Of these, usable data were obtained from 31 participants with no stimulation, 16 with “sham” stimulation, 16 with fronto-striatal (procedural) stimulation, and 16 with temporal (declarative) stimulation. As expected, we found that participants who had left temporal stimulation (targeting declarative pathways) learned the surface features of the grammar whereas those with front-striatal stimulation (targeting procedural pathways) learned the structure of the grammar and were more sensitive to frequent letter chunks than people who had frontal stimulation or sham stimulation (see Figure 8). These results were published in the Cognitive Science conference proceedings and a manuscript for journal publication is in preparation (Bice & Prat, 2020 and in prep).

Next, we repeated the experiment but replaced the artificial grammar task with a more naturalistic language task, learning French with Duolingo. This experiment involved four language learning sessions with concurrent tDCS stimulation to either left temporal lobes (N = 7) or fronto-striatal circuits (N=9) or sham stimulation (N =7). Preliminary results demonstrate an early and consistent advantage for temporal (declarative) stimulation during learning, such that learners receiving temporal stimulation make significantly fewer errors, ask for significantly fewer hints, and complete significantly more lessons on average than learners receiving sham stimulation. Data collection for this Duolingo experiment was supported in part by a postdoctoral fellowship awarded to trainee Kinsey Bice and is still in process.

3. What opportunities for training and professional development did the project provide?

A total of eight graduate students, one post baccalaureate and one postdoctoral trainee were involved with the research supported by this grant. Three graduate students were directly funded as Research Assistants. Margarita Zeitlin, a graduate student co-supervised by Dr. Prat and Lee Osterhout, was funded as a Research Assistant in 2019. During this time, Margarita received advanced training in fMRI analysis, attending an AFNI Training Opportunities bootcamp in which she learned how to analyze our resting-state fMRI data. Malayka Mottarella and Chu-Hsuan Kuo, graduate students supervised by Chantel Prat, were both funded as Research Assistants on the grant in 2020. During this time Malayka worked with postdoctoral fellow Kinsey Bice, to develop a new EEG analysis method which defines spectral bands based on an individual's alpha peak. Chu-Hsuan Kuo worked to develop new evaluation measurements for our Python training protocols while gaining more advanced knowledge of Python. Additionally, the grant provided many critical opportunities for all of our trainees to attend international conferences, present their work, and network with other scholars in their fields. Three graduate students, Brianna Yamasaki, Jose Ceballos, and Roy Seo successfully completed their dissertation work and accepted competitive postdoctoral (2) and industry (1) positions. We also recruited Kinsey Bice, a postdoctoral fellow funded by the University of Washington Research Foundation postdoctoral grant through the Institute for Neuroengineering. During this time Kinsey attended a computational modeling workshop hosted by the Allen Brain Institute in 2019. She has also received extensive training in neuroengineering over the past two year and has been key to developing our neurostimulation procedures in 2020.

4. How were the results disseminated to communities of interest?

Over the past three years we have had 10 papers published in a number of well respected journals including the Journal of Cognitive Neuroscience, Scientific Reports, Neurobiology of Language, Neuroimage, and Topics in Cognitive Sciences. We also have three papers under review or revision, and three more in preparation. Our results were also presented in 13 conference proceedings and accepted at international meetings such as the Cognitive Science Society, the Cognitive Neuroscience Society, the Society for Texts and Discourses, and the Society for the Neurobiology of Language. Together, Dr. Prat (PI) and the graduate students have also presented this work dozens of times, including during invited colloquia at the University of Colorado, Boulder and Mississippi State University, as well as many local colloquia.

5. Honors: What honors or awards were received under this project in the reporting period?

The students supported on this grant have been incredibly successful in their budding careers. Brianna Yamasaki, a former graduate student supported on this project, was awarded the University of Washington Distinguished Teaching Award in 2018. As a postdoctoral fellow at Vanderbilt University, Brianna, also received the Jason Albrecht Outstanding Young Scientist Award from the Society for Text and Discourse in 2019 for her doctoral work investigating the role of inhibitory control in bilingual reading. Jose Ceballos, a graduate student trained by Dr. Prat, received the Marr Prize for best student paper from the Cognitive Science Society in 2019, as well as the Diversity Award for travel to the conference. Jose, and fellow graduate student Roy Seo, also received travel awards from the Society for the Neurobiology of Language to present their research in 2018. Margarita Zeitlin, a graduate student funded on the award,

received the University of Washington Distinguished Teaching Award in 2019. Malayka Mottarella, who was previously a postbac in our lab before joining us as a graduate student in 2019, received the Graduate Student Research Award at the Society for Text and Discourse in 2020 for her work examining the relation between proactive control and reading.

6. Technology Transfer

N/A

7. Participants

Name	Role	Person
Chantel Prat	PD/PI	9
Andrea Stocco	Co PD/PI	2.2
Brianna Yamasaki	Graduate Student (research assistant)	3
Malayka Mottarella	Non-Student Research Assistant	27
Justin Abernethy	Other Professional	14.49
Margarita Zeitlin	Graduate Student (research assistant)	3.5
Malayka Mottarella	Graduate Student (research assistant)	1.25
Theodros Haile	Graduate Student (research assistant)	1.34

8. Students

Number Science, Technology, Engineering and Mathematics (STEM) participants: 5
 Number of participants that received a STEM degree: 2

9. Products

Below is the information detailed for each product submission:

Papers

Prat, C. S., Madhyastha, T. M., Mottarella, M. J., & Kuo, C. (2020). Relating natural language aptitude to individual differences in learning programming languages. *Scientific Reports*, 10(1), 1-10.

1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)
 - a. Relating natural language aptitude to individual differences in learning programming language
 - b. Scientific Reports
 - c. Chantel S. Prat, Tara M. Madhyastha, Malayka J. Mottarella, Chu-Hsuan Kuo
 - d. NA
 - e. Approved for public release: distribution unlimited.
 - f. Published

- g. DOI
- h. <https://doi.org/10.1038/s41598-020-60661-8>
- i. March 2020
- j. 10
- k. 3817
- l. 1
- m. London, UK
- n. Yes
- o. Yes

Bice, K., Yamasaki, B. L., & Prat, C. S. (2020). Bilingual language experience shapes resting-state brain rhythms. *Neurobiology of Language*, 1(3), 288-318.

- 1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)
 - a. Bilingual language experience shapes resting-state brain rhythms
 - b. Neurobiology of Language
 - c. Kinsey Bice, Brianna L. Yamasaki, Chantel S. Prat
 - d. Bilingualism, neural oscillations, resting-state, EEGs
 - e. Approved for public release: distribution unlimited.
 - f. Published
 - g. DOI
 - h. https://doi.org/10.1162/nol_a_00014
 - i. July 2020
 - j. 1
 - k. 3
 - l. 288

- m. Amsterdam, Netherlands
- n. Yes
- o. Yes

Ceballos, J. M., Stocco, A., & Prat, C. S. (2020). The role of basal ganglia reinforcement learning in lexical ambiguity resolution. *Topics in Cognitive Science*, 12(1), 402-416.

1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)
 - a. The role of basal ganglia reinforcement learning in lexical ambiguity resolution.
 - b. Topics in Cognitive Science
 - c. Jose M. Ceballos, Andrea Stocco, Chantel S. Prat
 - d. Language, semantics, lexical selection, ambiguity resolution, priming, reinforcement learning, basal ganglia, dopamine, cognitive modeling, ACT-R
 - e. Approved for public release: distribution unlimited.
 - f. Published
 - g. ISSN
 - h. 1756-8765 online
 - i. January 2020
 - j. 12
 - k. 1
 - l. 402
 - m. NA
 - n. Yes
 - o. Yes

Prat, C. S., Yamasaki, B. L., & Peterson, E. R. (2019). Individual differences in resting-state brain rhythms uniquely predict second language learning rate and willingness to communicate in adults. *Journal of Cognitive Neuroscience*, 31(1), 78-94.

1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)

- a. Individual differences in resting-state brain rhythms uniquely predict second language learning rate and willingness to communicate in adults.
- b. Journal of Cognitive Neuroscience
- c. Chantel S. Prat, Brianna L. Yamasaki, Erica R. Peterson
- d. NA
- e. Approved for public release: distribution unlimited.
- f. Published
- g. ISSN
- h. 0898-929X
- i. January 2019
- j. 31
- k. 1
- l. 78
- m. Cambridge, MA
- n. Yes
- o. Yes

Seo, R. & Prat, C. S. (2019). Proactive and reactive language control in the bilingual brain. *Brain Sciences*, 9(7), 1-20.

- 1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)
 - a. Proactive and reactive language control in the bilingual brain
 - b. Brain Sciences
 - c. Roy Seo, Chantel S. Prat
 - d. Bilingual language control, proactive control, reactive control, anterior cingulate cortex, basal ganglia, dorsolateral prefrontal cortex
 - e. Approved for public release: distribution unlimited.
 - f. Published
 - g. DOI

- h. <https://doi.org/10.3390/brainsci9070161>
- i. July 2019
- j. 9
- k. 7
- l. 1
- m. NA
- n. Yes
- o. Yes

Yamasaki, B. L., Stocco, A., & Prat, C. S.(2018). Relating individual differences in bilingual language experiences to executive attention. *Language, Cognition, and Neuroscience*, 33(9), 1-24.

- 1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)
 - a. Relating individual differences in bilingual language experiences to executive attention.
 - b. Language, Cognition, and Neuroscience
 - c. Brianna L. Yamasaki, Andrea Stocco, Chantel S. Prat
 - d. Bilingualism, executive attention, attentional blink, individual differences
 - e. Approved for public release: distribution unlimited.
 - f. Published
 - g. DOI
 - h. <https://doi.org/10.1080/23273798.2018.1448092>
 - i. March 2018
 - j. 33
 - k. 9
 - l. 1128
 - m. United Kingdom
 - n. Yes
 - o. Yes

Seo, R., Stocco, A., & Prat, C. S. (2018). The bilingual language network: Differential involvement of anterior cingulate, basal ganglia and prefrontal cortex in preparation, monitoring, and execution. *Neuroimage*, 174, 44-56.

1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)
 - a. The bilingual language network: Differential involvement of anterior cingulate, basal ganglia and prefrontal cortex in preparation, monitoring, and execution.
 - b. NeuroImage
 - c. Roy Seo, Andrea Stocco, Chantel S. Prat
 - d. Anterior cingulate cortex, basal ganglia, bilingualism, cognitive control, prefrontal cortex, functional magnetic resonance imaging
 - e. Approved for public release: distribution unlimited.
 - f. Published
 - g. ISSN
 - h. 1053-8119
 - i. February 2018
 - j. 174
 - k. NA
 - l. 44
 - m. Amsterdam, Netherlands
 - n. Yes
 - o. Yes

Stocco, A., Yamasaki, B. L., & Prat, C. S. (2018). Human performance across decision making, selective attention, and working memory tasks: Experimental data and computer simulations. *Data in Brief*, 17, 907-914.

1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)
 - a. Human performance across decision making, selective attention, and working memory tasks: Experimental data and computer simulations.

- b. Data in Brief
- c. Andrea Stocco, Brianna L. Yamasaki, Chantel S. Prat
- d. NA
- e. Approved for public release: distribution unlimited.
- f. Published
- g. DOI
- h. <https://doi.org/10.1016/j.dib.2018.01.056>
- i. February 2018
- j. 17
- k. NA
- l. 907
- m. Amsterdam, Netherlands
- n. Yes
- o. Yes

Stocco, A., Murray, N. L., Yamasaki, B. L., Renno, T. J., Nguyen, J., & Prat, C. S. (2017). Individual differences in the Simon effect are underpinned by differences in the competitive dynamics in the basal ganglia: An experimental verification and a computation model. *Cognition*, 164, 31-45.

- 1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)
 - a. Individual differences in the Simon effect are underpinned by differences in the competitive dynamics in the basal ganglia: An experimental verification and a computation model.
 - b. Cognition
 - c. Andrea Stocco, Nicole L. Murray, Brianna L. Yamasaki, Taylor J. Renno, Jimmy Nguyen, Chantel S. Prat
 - d. Cognitive control, selective attention, prefrontal cortex, basal ganglia, computation modeling
 - e. Approved for public release: distribution unlimited.
 - f. Published

- g. DOI
- h. <http://dx.doi.org/10.1016/j.cognition.2017.03.001>
- i. March 2017
- j. 17
- k. NA
- l. 907
- m. Amsterdam, Netherlands
- n. Yes
- o. Yes

Prat, C. S., Gallée, J., & Yamasaki, B. L. (In prep). Getting language learning right: The role of the right hemisphere in language aptitude. *Brain and Language*

- 1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)
 - a. Getting language learning right: The role of the right hemisphere in language aptitude
 - b. Brain and Language
 - c. Chantel S. Prat, Jeanne Gallée, Brianna L. Yamasaki
 - d. Language learning; right hemisphere
 - e. NA.
 - f. In prep for invited submission due Sept 7
 - g. NA
 - h. NA
 - i. NA
 - j. NA
 - k. NA
 - l. NA
 - m. NA
 - n. Yes

o. Yes

Mottarella, M., Yamasaki, B. L., & Prat, C. S. (In prep). Relating neural indices of proactive control, filtering, and disengagement to individual differences in reading skill.

1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)
 - a. Relating neural indices of proactive control, filtering, and disengagement to individual differences in reading skill.
 - b. Discourse Processes
 - c. Malayka Mottarella, Brianna L. Yamasaki, Chantel S. Prat
 - d. Proactive control; working memory; reading skill; individual differences
 - e. NA.
 - f. In prep for special issue due Sept 7
 - g. NA
 - h. NA
 - i. NA
 - j. NA
 - k. NA
 - l. NA
 - m. NA
 - n. Yes
 - o. Yes

Bice, K. & Prat, C. S. (In prep). Using neurostimulation to engage declarative and procedural pathways during artificial grammar learning

1. Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)
 - a. Using neurostimulation to engage declarative and procedural pathways during artificial grammar learning.
 - b. NA
 - c. Kinsey Bice, Chantel S. Prat

- d. Neurostimulation; tDCS; declarative learning; procedural learning; artificial grammar
- e. NA.
- f. NA
- g. NA
- h. NA
- i. NA
- j. NA
- k. NA
- l. NA
- m. NA
- n. Yes
- o. Yes

Prat, C. S., Mottarella, M., Bice, K., Yamasaki, B. L., Snitsar, O., & Stocco, A. (In prep).
Neuropsychometrics: Exploring the measurement characteristics of resting-state EEG metrics recorded with Emotiv EPOC headsets.

Publications (publication reference information (article title, authors, journal, date, volume, issue) can be automatically entered using a DOI)

- a. Neuropsychometrics: Exploring the measurement characteristics of resting-state EEG metrics recorded with Emotiv EPOC headsets.
- b. NA
- c. Chantel S. Prat, Malayka Mottarella, Kinsey Bice, Brianna L. Yamasaki, Olga Snitsar, Andrea Stocco
- d. Resting-state; EEG; reliability
- e. NA.
- f. NA
- g. NA
- h. NA
- i. NA

- j. NA
- k. NA
- l. NA
- m. NA
- n. Yes
- o. Yes

Posters

Bice, K. & Prat, C.S. (2020). *Comparing the Effects of Frontal and Temporal Neurostimulation on Second Language Learning*. Poster presented at the Annual Meeting of the Cognitive Science Society, Virtual Conference.

- 2. Conference Poster
 - a. Comparing the Effects of Frontal and Temporal Neurostimulation on Second Language Learning.
 - b. Kinsey Bice, Chantel S. Prat
 - c. Cognitive Science Society
 - d. July 30-Aug 1 2020
 - e. Virtual
 - f. Other
 - g. NA
 - h. NA
 - i. NA
 - j. Yes

Mottarella, M.& Prat, C.S. (2020) *Understanding the Neurocognitive Mechanisms of Maintenance and Disengagement in a Complex Working Memory Task*. Poster presented at the Annual Meeting of the Cognitive Neuroscience Society, Virtual Conference.

- 2. Conference Poster
 - a. Understanding the Neurocognitive Mechanisms of Maintenance and Disengagement in a Complex Working Memory Task.

- b. Malayka Mottarella, Chantel S. Prat
- c. Cognitive Neuroscience Society
- d. May 2-5 2020
- e. Virtual
- f. Other
- g. NA
- h. NA
- i. NA
- j. Yes

Bice, K. & Prat, C.S. (2020) *Transcranial Direct Current Stimulation Influences Reliance on Declarative vs. Procedural Learning*. Poster presented at the Annual Meeting of the Cognitive Neuroscience Society, Virtual Conference.

- 2. Conference Poster
 - a. Transcranial Direct Current Stimulation Influences Reliance on Declarative vs. Procedural Learning.
 - b. Kinsey Bice, Chantel S. Prat
 - c. Cognitive Neuroscience Society
 - d. May 2-5 2020
 - e. Virtual
 - f. Other
 - g. NA
 - h. NA
 - i. NA
 - j. Yes

Prat, C. S., Zeitlin, M., Mottarella, M., Yamasaki, B., & Madhyastha, T.. (2019, March) *Relating Individual Differences in Beta Oscillations Recorded at Rest to Second Language Aptitude and Basal Ganglia Signal Routing*. Poster presented at the Annual Meeting of the Cognitive Neuroscience Society, San Francisco, CA.

2. Conference Poster
 - a. Relating Individual Differences in Beta Oscillations Recorded at Rest to Second Language Aptitude and Basal Ganglia Signal Routing.
 - b. Chantel S. Prat, Margarita Zeitlin, Malayka Mottarella, Brianna L. Yamasaki, Tara Madhyastha
 - c. Cognitive Neuroscience Society
 - d. March 23-26 2019
 - e. San Francisco, CA
 - f. Other
 - g. March 2019
 - h. NA
 - i. NA
 - j. Yes

Conference Papers

Haile, T., Prat, C. S., & Stocco, A. (2020). *One Size Doesn't Fit All: Idiographic Computational Models Reveal Individual Differences In Learning and Meta-Learning Strategies*. Conference Paper at the International Conference on Cognitive Modeling, Virtual Conference.

2. Conference Paper
 - a. One Size Doesn't Fit All: Idiographic Computational Models Reveal Individual Differences In Learning and Meta-Learning Strategies.
 - b. Theodoros Haile, Chantel S. Prat, Andrea Stocco
 - c. International Conference on Cognitive Modeling
 - d. July 20-31 2020
 - e. Virtual
 - f. Other
 - g. NA
 - h. NA
 - i. NA

j. Yes

Mottarella, M., Yamaski, B. L., & Prat, C.S. (2020) *Skilled Readers Engage More Proactive Attentional Control During a Working Memory Task*. Oral presentation given at the 30th Annual Meeting of the Society for Texts and Discourse, Virtual Conference.

2. Conference Paper

a. Skilled Readers Engage More Proactive Attentional Control During a Working Memory Task

b. Malayka Mottarella, Brianna L. Yamasaki, Chantel S. Prat

c. Society for Texts and Discourse

d. July 22-23 2020

e. Virtual

f. Other

g. NA

h. NA

i. NA

j. Yes

Ceballos, J. M., Stocco, A., & Prat, C.S. (2019) *The Role of Basal Ganglia Reinforcement Learning in Lexical Priming and Automatic Semantic Ambiguity Resolution*. In A. Goel., C. Freisert, & C. Freska (Eds.) *Proceedings of the 41st Annual Meeting of the Cognitive Science Society*, pp. 205–211. [Winner of the Marr prize for best student paper]

2. Conference Paper

a. The Role of Basal Ganglia Reinforcement Learning in Lexical Priming and Automatic Semantic Ambiguity Resolution.

b. Jose M. Ceballos, Andrea Stocco, Chantel S. Prat

c. Cognitive Science Society

d. July 24-27 2019

e. Montreal, Canada

f. Other

- g. NA
- h. NA
- i. NA
- j. Yes

Prat, C. S., Mottarella, M., & Yamasaki, B. L. (2018). *Working Memory Filtering and Individual Differences in Second Language Aptitude*. Poster session presented at the Annual Meeting of the Society for Neurobiology of Language, Quebec City, Canada.

- 2. Conference Paper
 - a. Working Memory Filtering and Individual Differences in Second Language Aptitude
 - b. Chantel S. Prat, Malayka Mottarella, Brianna L. Yamasaki
 - c. Society for Neurobiology of Language
 - d. August 2018
 - e. Quebec City, Canada
 - f. Other
 - g. August 2018
 - h. NA
 - i. NA
 - j. Yes

Prat, C. S. & Yamasaki, B. L. (2018). *Resting-state qEEG reveals intrinsic network differences between monolingual and bilingual adults*. *The Bilingual Brain, A Lifelong Perspective*, Quebec City, Canada

- 2. Conference Paper
 - a. Cortical Dynamics and Individual Differences in Reading: Relating Beta Oscillations with Reading Skill.
 - b. Chantel S. Prat, Brianna L. Yamasaki
 - c. The Bilingual Brain, A Lifelong Perspective
 - d. August 2018.

- e. Quebec City, Canada
- f. Other
- g. August 2018
- h. NA
- i. NA
- j. Yes

Figures

Figure 1: Resting state beta power is positively correlated with basal ganglia connectivity in resting-state fMRI.

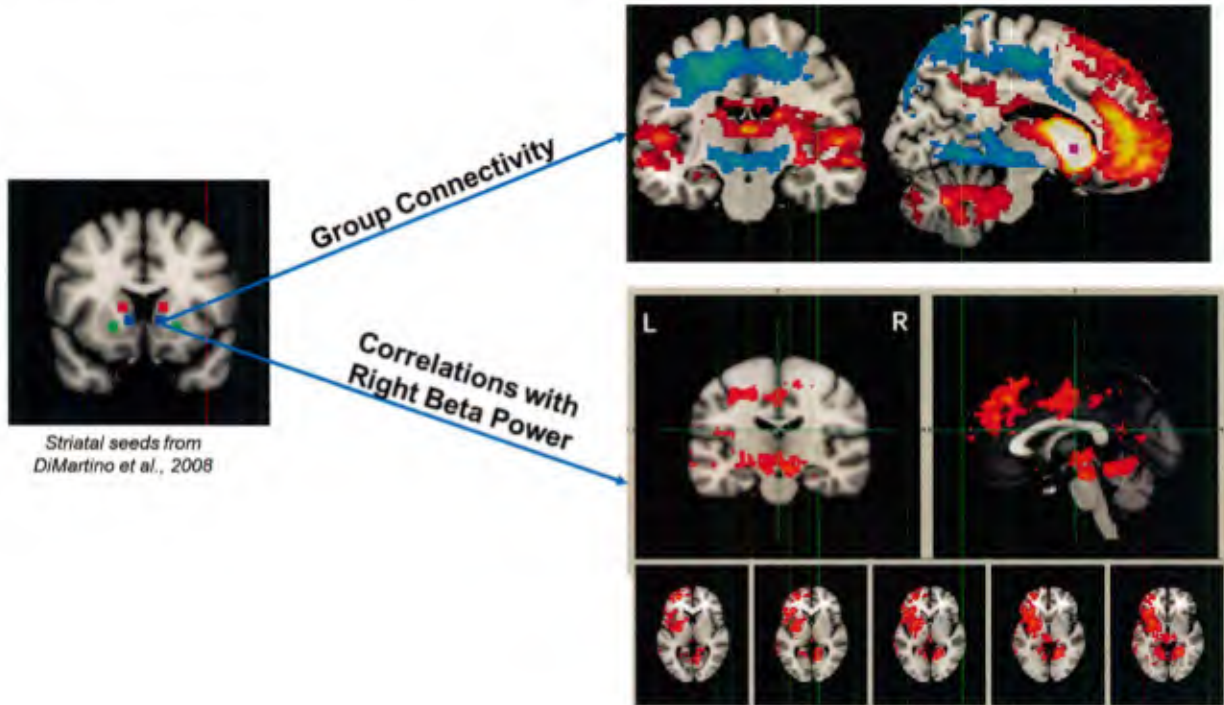


Figure 2: Individual differences in python learning rate

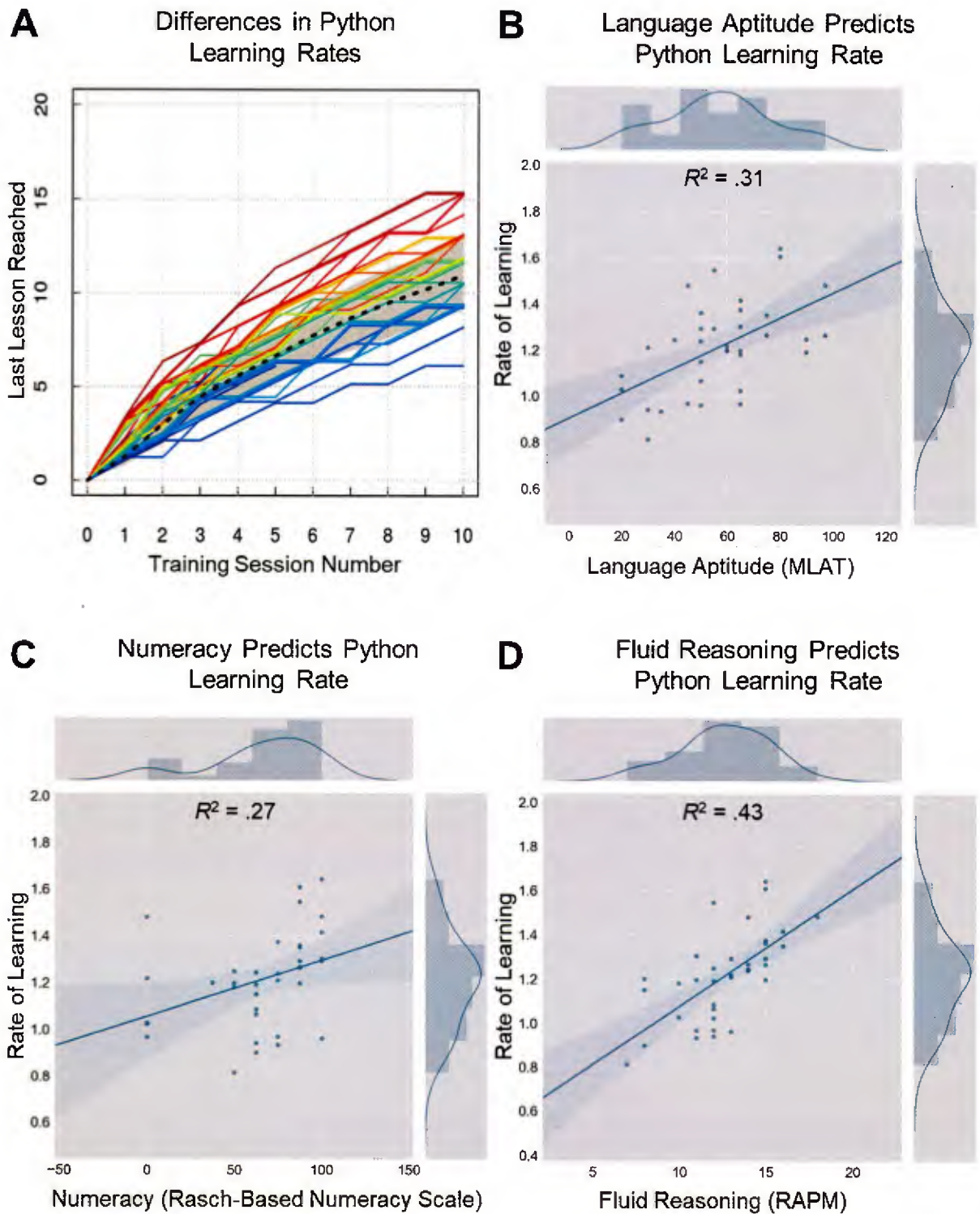


Figure 3: Relative utility of various predictor types for three python outcomes

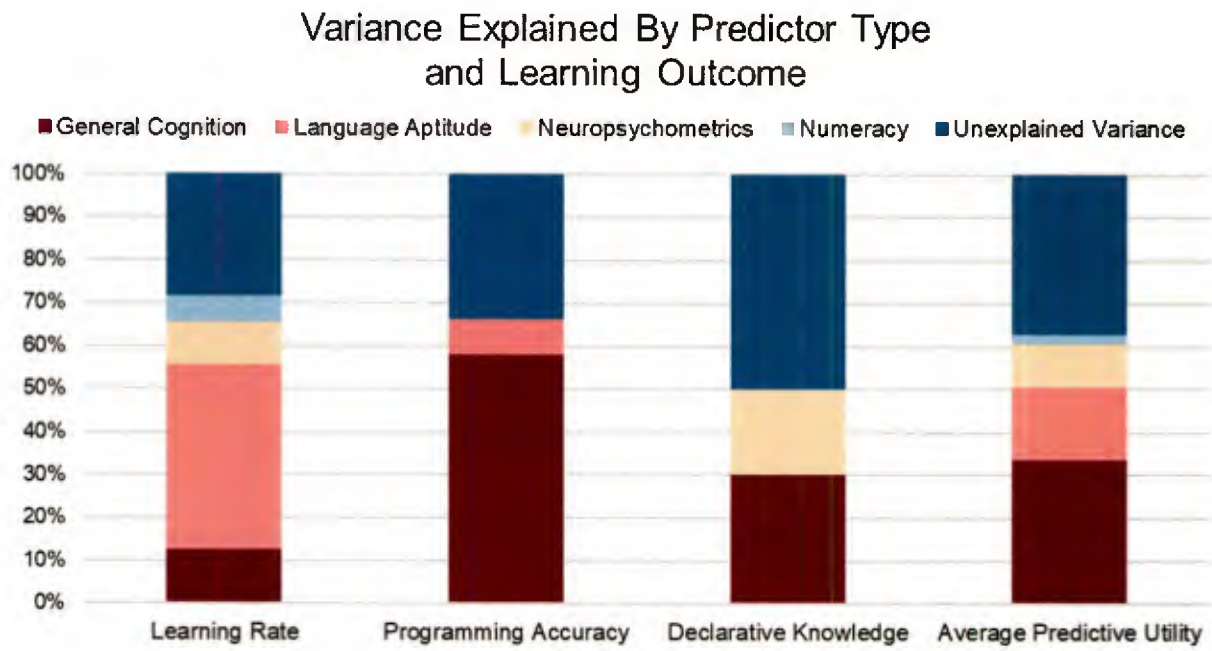


Figure 4: Positive correlation between python and French learning outcomes
Programming Accuracy vs. Post-Test Vocabulary (French)

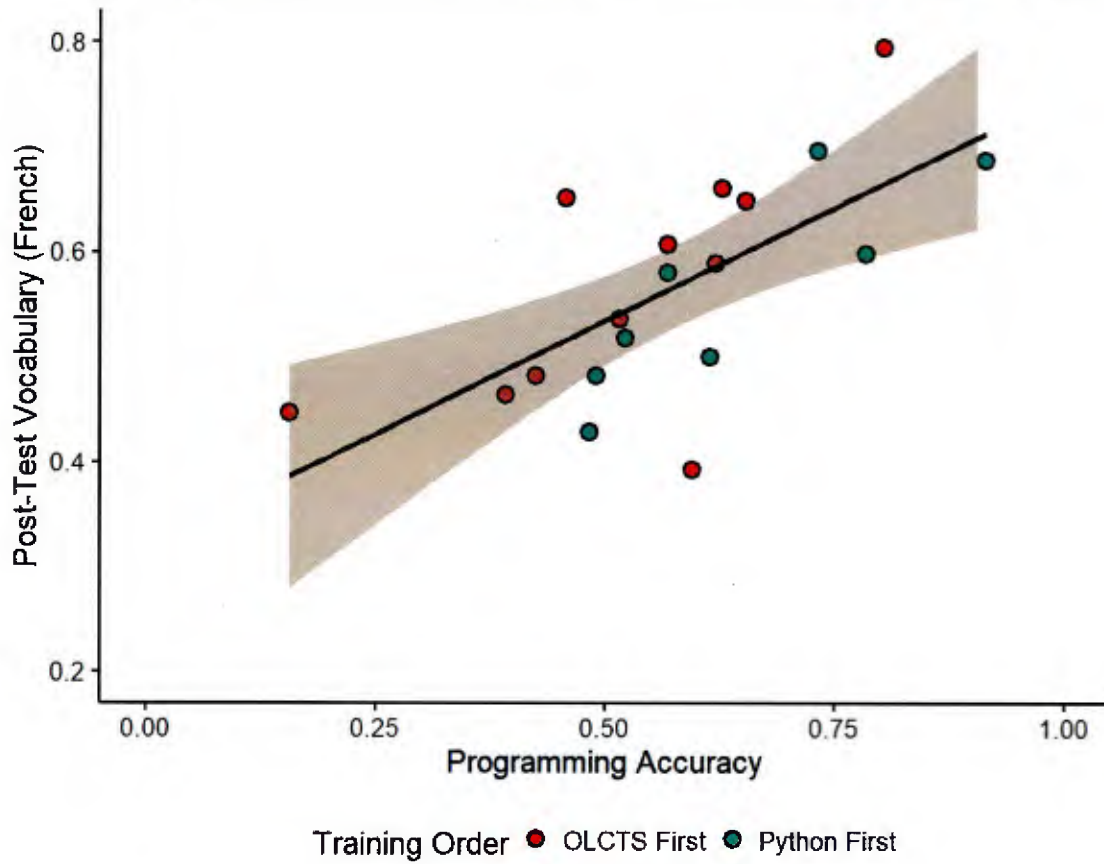


Figure 5: Overview of one model that employ both reinforcement and declarative learning strategies and uses meta-learning to arbitrate between strategies

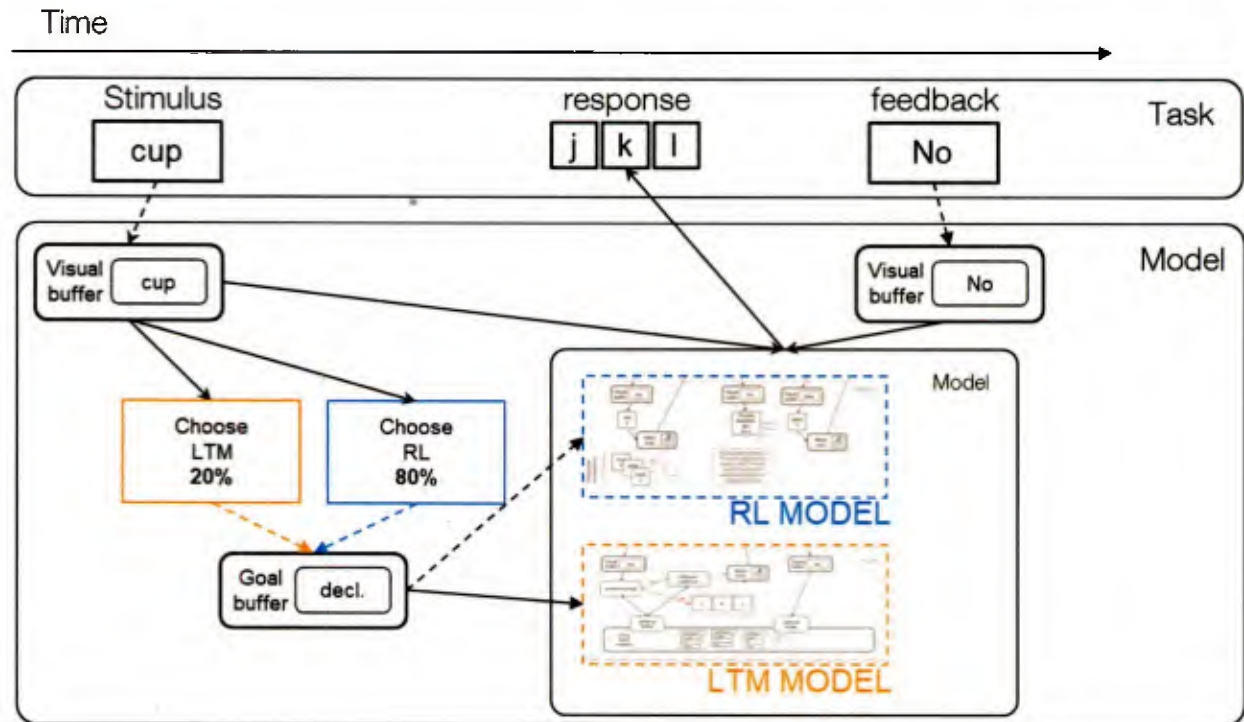


Figure 6: Counts of the number of participants that are best matched by each of the learning strategy models

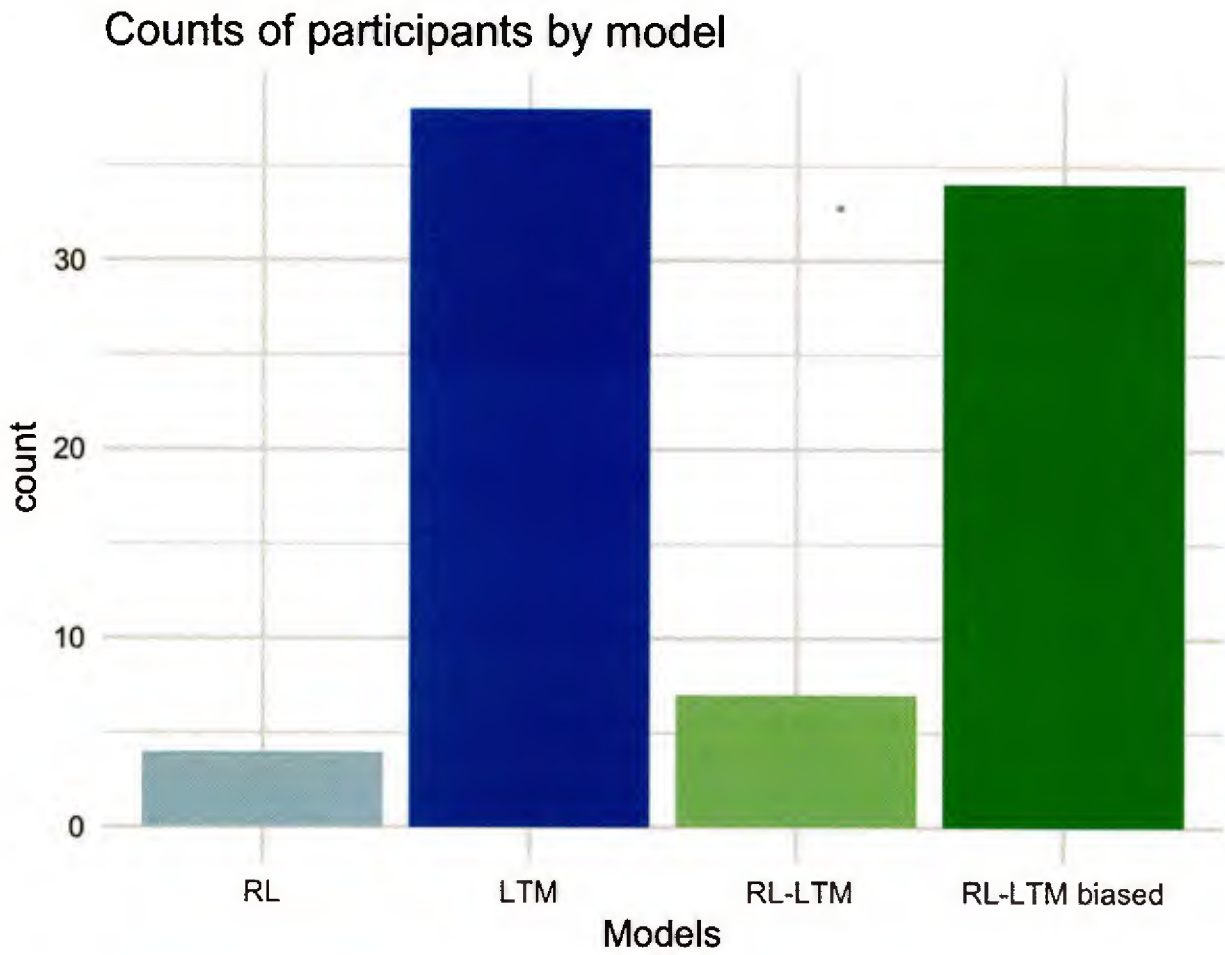


Figure 7: Unique resting state fMRI predictors of vocabulary learning and grammatical proficiency.

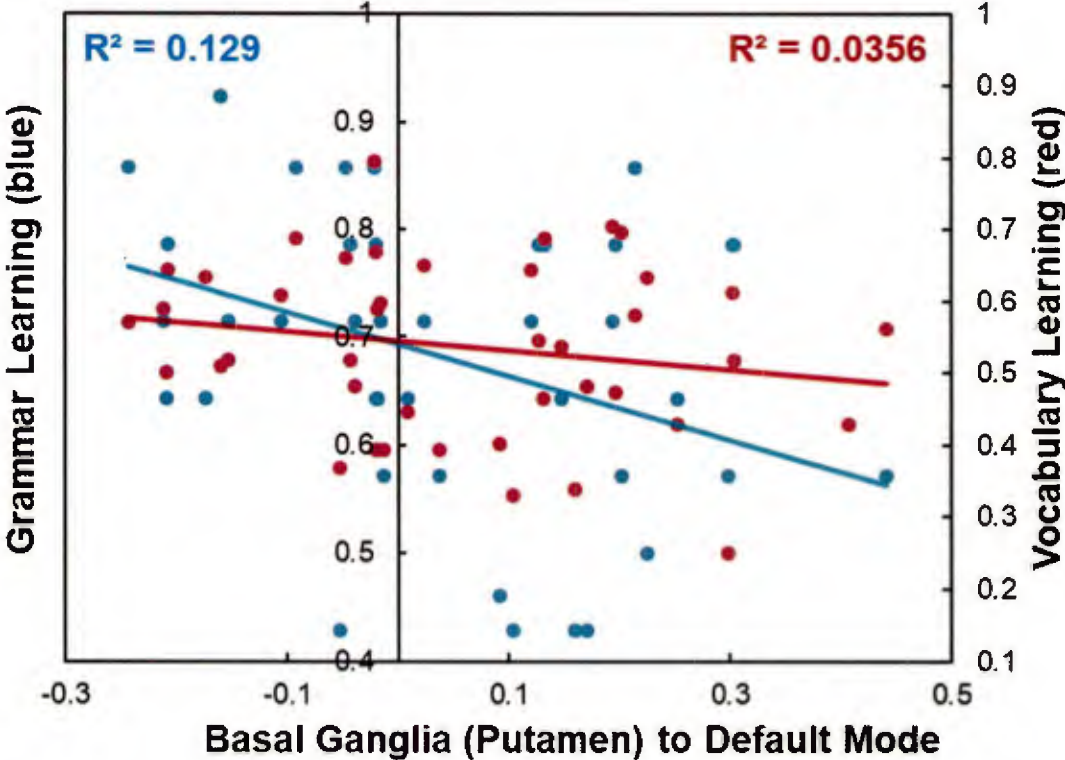


Figure 8: Unique resting state fMRI predictors of vocabulary learning and grammatical proficiency.

