

**REPORT DOCUMENTATION PAGE**

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<b>1. REPORT DATE (DD-MM-YYYY)</b> 02/23/2018		<b>2. REPORT TYPE</b> Final		<b>3. DATES COVERED (From - To)</b> 06-01-2014 - 08-30-17	
<b>4. TITLE AND SUBTITLE</b> Training the Mind and Brain: Investigating Individual Differences in the Ability to Learn and Benefit Cognitively from Language Training				<b>5a. CONTRACT NUMBER</b>	
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<b>6. AUTHOR(S)</b> Chantel S. Prat and Andrea Stocco				<b>5d. PROJECT NUMBER</b> 1000004959	
				<b>5e. TASK NUMBER</b>	
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<b>12. DISTRIBUTION/AVAILABILITY STATEMENT</b> Approved for public release. Distribution is unlimited					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> Learning a second language (L2) in adulthood is difficult but often desirable, and large individual differences exist in the ability to do so. Our funded program of research looked at the neurocognitive predictors of such L2 aptitude in healthy young adults. Across several experiments we showed that neural indexes outperformed behavioral measures when predicting subsequent L2 learning. We also showed that learning a second language creates changes in both brain functioning and cognitive abilities, at least in the short term. Finally, through our computational modeling efforts, we created a critical modification to the ACT-R architecture that allows us to account for individual differences in complex skill learning.					
<b>15. SUBJECT TERMS</b> individual differences, complex skill learning, second language aptitude, bilingualism					
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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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**4. TITLE.** Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

**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.

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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.

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**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.

Chantel Prat (PI) and Andrea Stocco (Co-PI)

University of Washington

Department of Psychology

ONR Award # N000141410344 and N00014-16-1-2610

ONR Award Title: Training the Mind and Brain: Investigating Individual Differences in the Ability to Learn and Benefit Cognitively from Language Training

Final Technical Report 6/1/14-8/30/17

**1. What were the major goals and objectives of this project? (8000characters- can be expanded perhaps to include approach)**

Language is one of the most complex feats of the human brain, involving the representation, retrieval, and manipulation of symbolic codes for producing a nearly infinite set of communicative structures. Bilingualism increases the neurocognitive demands associated with language use, as it requires the selection and manipulation of multiple sets of co-activated codes and rules that interface with a largely overlapping meaning system. Individual differences research has shown that not all bilinguals are equally successful in meeting these demands, and that general executive functioning predicts how well bilingual individuals can “control” the use of their two languages (Festman, Rodriguez-Fornells & Münte, 2010). Because bilingualism increases demands for interference management, it has also been suggested that such bilingual language experience may have broader consequences for training the mind (e.g., Bialystok, Craik & Luk, 2012) and shaping the brain (e.g., Stocco & Prat, 2014; Stocco, Yamasaki, Natalenko, & Prat, 2014). Our program of research had three interrelated goals centered around a proposed, network-level mechanism for controlling multiple languages in the brain: **(1)** to investigate the impact of learning a second language in adulthood on neural functioning and on general cognitive abilities, **(2)** to relate individual differences in neural functioning to the ability to acquire a second language in adulthood, and **(3)** to develop a biologically-based computational model of complex skill learning that can ultimately account for second language acquisition in adulthood. Such modeling has important implications for research on language, learning, and neural plasticity, and has broad applications for education and industry, where language aptitude has been a desirable trait to measure.

To achieve these goals, our program applied iterative neuroimaging and behavioral experimental research with computational modeling efforts. A central feature of the experimental work is 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 and cultural immersion software. The OLCT system provides a rich language experience, including tests of auditory comprehension and speech production as well as the more traditional, memory-based tests of item recognition. To measure the impact of learning a second language on mind and brain, we had participants complete a large battery of standard psychometric tests, and then exposed them to 16 training sessions with the OLCT. Following training, parallel versions of these tests were re-administered. This research was conducted as proposed, with the important addition of an index of brain functioning (quantitative electroencephalography, or qEEG) which has proven to be quite informative (see results below). This data allowed us to conduct separate analyses in line with two goals: **(1)** to measure changes in brain and behavior that occurred following language training, and **(2)** to use indices of neural

functioning and cognitive abilities conducted at baseline to predict ultimate language proficiency. No significant changes in approach have happened or are to be expected.

**2. What was accomplished toward achieving these goals? (8000 characters, no figures, attached separately)**

Across the funding period, we tested over 100 individuals in longitudinal experiments aimed at predicting individual differences in the ability to learn a second language, and at measuring and modeling changes in brain and behavior associated with such learning. The results of this three-year research program resulted in 11 publications in high-impact journals and dozens of conference proceedings and media mentions. Perhaps the highest impact of this research was the development and testing of a neuropsychometric battery that predicts second language aptitude above and beyond the gold-standard behavioral measures. This research has been highly impactful in the field, and leaders in the field of bilingualism and second language aptitude have been reaching out for collaborations.

**Goal 1: To investigate the effects of learning a second language on behavioral and neural indices of general cognitive functioning.** Across our funding window, we trained 49 participants to speak Sub-Saharan French using the OLCTS software developed by the ONR. Our results show that L2 language exposure significantly improves executive functioning (including Simon Task performance as modeled for goal 3) and working memory scores, as compared to either working memory training or no-contact controls (see Figure 1). We also found significant changes in resting state EEG (primarily in the left fronto-temporal regions across beta and gamma frequencies) following such language training (Figure 2), and that these increases in beta power were also correlated with how much language training an individual received. A preliminary version of these results was presented at the Organization for Human Brain Mapping (Yamasaki & Prat, 2015).

**Goal 2: To investigate predictors of individual differences in second language (L2) aptitude.** Results aimed at discovering the neural predictors of L2 aptitude have been remarkably successful. In particular, we were the first lab in the world to report that data obtained from EEG while participants closed their eyes for five minutes could predict with remarkable accuracy both rate of L2 learning (Figure 3) and subsequent speaking accuracy (Figure 4). Our work has also shown that indices of brain structure (Figure 5) and function (Figure 6) collected with magnetic resonance imaging can be related to subsequent L2 learning. We plan to follow up on these exciting results by using machine learning techniques to integrate data collected across modalities to form better predictors of L2 learning.

**Goal 3: To develop and test neurocomputational models linking bilingualism and general cognitive processes.** The computational modeling efforts of this grant have taken two forms. First, dynamic causal modeling (DCM) of fMRI data (Friston, Harrison & Penny, 2003) was conducted to better understand the impacts of bilingualism on mind and brain. Specifically, we investigated the claim on which the current proposal is based, that bilingual language experience drives the influence of the basal ganglia on prefrontal regions. To test this, DCM analyses were conducted on a data set collected while bilingual and monolingual individuals completed a mathematical rule task (Stocco & Prat, 2014). We found that bilingual and monolingual individuals showed different patterns of effective connectivity between brain regions known to underlie executive control. Specifically, the influence of the anterior cingulate cortex on basal ganglia and dorsolateral prefrontal cortex (DLPFC) and the influence of the basal

ganglia on DLPFC was significantly different in monolinguals and bilinguals (see Figure 4). These results were published in *Neuropsychologia* during the report period (Becker, Stocco, & Prat, 2016).

Second, our modeling efforts were critically advanced by the development of a new framework within the ACT-R architecture. Specifically, to test the proposed relationship between basal ganglia signal routing in bilingual individuals and improvements in executive functioning, ACT-R was modified to include a more realistic model of basal ganglia function. This modification is firmly grounded in the neurobiology of the fronto-striatal circuitry, which contains at least two pathways: (1) A direct pathway modulated by D1 dopamine receptors which has an overall excitatory effect on signals traveling to the prefrontal cortex, and (2) an indirect pathway modulated by D2 dopamine receptors, which has an overall inhibitory connection on signals traveling to the prefrontal cortex. Previous research has shown that learning involves separable contributions of direct (D1) pathways and indirect (D2) pathways, which correspond to learning about the likelihood that an action will be rewarding (D1) and learning about the likelihood that an action will not be rewarding (D2). These contributions can be measured through a simple behavioral task, whose results have been linked to the functioning of the two pathways through behavioral genetics and pharmacological investigations. In fact, we have shown that accounting for this distinction is not only essential to model human data, but might also have an evolutionary reason, since it significantly reduces optimistically biased estimates of future rewards in Reinforcement Learning models (Rice & Stocco, 2017). To reflect these fundamental features of the basal ganglia, ACT-R was modified to allow for two independent and competing sets of production rules. One set reflects the contribution of the direct pathway, and consists of production moving information into working memory buffers. The other set reflects the indirect pathway and consists of productions protecting working memory buffers. Learning in the two sets of productions follows the same reinforcement learning-like rules, but is controlled by two different rate parameters, reflecting individual differences in the expression of D1 and D2 receptors. This implementation was tested in a new model (Figure 7) that accounts for data obtained from our L2 learning prediction study, and correctly demonstrating that sensitivity to actions that are not rewarding (D2) covaries with performance on the Simon Task (Figure 8). This model represents a critical change in the ACT-R architecture toward a system of action selection that is more firmly grounded in cognitive neuroscience. Additionally, the model of the Simon Task is critical to the 3<sup>rd</sup> aim of this proposal, as it is the most frequently used measure of executive functioning to demonstrate the influences of bilingual experience on cognitive control.

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

Two graduate students, Brianna Yamasaki and Roy Seo received research assistant funding as part of this grant that was critical to their training and completion of a Ph.D. in Cognitive Psychology. Yamasaki will graduate in May, and has secured a postdoc position at Vanderbilt University, where she will continue to understand the impact of bilingualism on the mind and brain by looking at children developing monolingually and bilingually. Seo will graduate in Fall of 2018, and recently had her first author manuscript (supported in part by this proposal) accepted for publication in *Neuroimage*. We also mentor dozens of undergraduate volunteers from diverse backgrounds in the execution of this program of research.

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

The results from this program of research have been published (or are being reviewed) in top journals such as Neuroimage, Cognition, the Journal of Cognitive Neuroscience, and Brain and Language. Our results have also been presented dozens of times at international conferences such as the Society for the Neurobiology of Language, Organization for Human Brain Mapping, and the International Conference on Cognitive Modeling). These results have also received quite a bit of coverage in the media. Press releases both at the University of Washington and through the Office of Naval research resulted in the story being picked up through international news outlets including: Science Daily, Science Blog, The Sun Daily, Quartz, Neuroscience News, Newswise, EurekAlert, The Daily Mail (UK), CTV News (Canada), The Australian, Language Magazine, Futurity, Egypt Independent, Malaysia Digest, and DNA India. Additionally, these have been discussed in two Scientific American articles including one written on Unsupervised Learning by Doug Fields, and another specifically about second language aptitude.

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

Dr. Chantel Prat was awarded tenure at the University of Washington in September of 2015. She also received a Research Royalty Funding Award (\$40,000) to pilot research using Neurofeedback training to improve attention and support learning. Brianna Yamasaki, a graduate student funded on this award, received the Distinguished Teaching Award from the Department of Psychology at the University of Washington, and also received the Stroum Fellowship (\$44,586) which covers her stipend, tuition, and health care during the completion of her dissertation research and writing in 2016-2017, and an Earl B. Hunt fellowship for her dissertation research.

#### **6. Technology Transfer**

N/A

#### **7. Participants**

N/A

#### **8. Students**

#### **9. Products**

Below is the information detailed for each product submission with most recent first:

1. Ceballos, J., Stocco, A., & Prat, C.S. (under revision) Reviewing the role of the basal ganglia in language: A contextual timed gating theory.
  - a. Reviewing the role of the basal ganglia in language: A contextual timed gating theory
  - b. NA
  - c. Jose Ceballos, Andrea Stocco, Chantel S Prat
  - d. basal ganglia, language, syntax, biligualism
  - e. Approved for public release: distribution unlimited.
  - f. Under Review
  - g. NA
  - h. NA

- i. NA
  - j. NA
  - k. NA
  - l. NA
  - m. NA
  - n. Yes
  - o. Yes
2. Seo, R., Stocco, A., & Prat, C. S. (in press). The bilingual language network: Differential involvement of anterior cingulate, basal ganglia and prefrontal cortex in preparation, monitoring, and execution. *NeuroImage*.
- 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. Awaiting Publication
  - g. NA
  - h. NA
  - i. NA
  - j. NA
  - k. NA
  - l. NA
  - m. NA
  - n. Yes
  - o. Yes
3. Stocco, A. (In press). A biologically-plausible action selection system for cognitive architectures: Implications of basal ganglia anatomy for learning and decision-making models. *Cognitive Science*.
- a. A biologically-plausible action selection system for cognitive architectures: Implications of basal ganglia anatomy for learning and decision-making models.
  - b. Cognitive Science
  - c. Andrea Stocco
  - d. cognitive modeling; decision making; cognitive architecture; dopamine; basal ganglia
  - e. Approved for public release: distribution unlimited.
  - f. Published
  - g. DOI
  - h. 10.1111/cogs.12506
  - i. 06/06/2017
  - j. NA
  - k. NA
  - l. NA
  - m. Hoboken, New Jersey
  - n. Yes

- o. Yes
4. Stocco, A., Yamasaki, B. L., & Prat, C. S. (in press). Correlations of human performance in three cognitive tasks: Experimental data and computer simulations. Data in Brief.
- a. Correlations of human performance in three cognitive tasks: Experimental data and computer simulations.
  - b. Data in Brief
  - c. Andrea Stocco, Brianna L Yamasaki, Chantel S Prat
  - d. cognitive modeling; executive function; selective attention; reinforcement learning; decision making
  - e. Approved for public release: Distribution Unlimited
  - f. Published
  - g. NA
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  - i. NA
  - j. NA
  - k. NA
  - l. NA
  - m. Amsterdam, Netherlands
  - n. Yes
  - o. Yes
5. Prat, C. S., Yamasaki, B. L., & Peterson, E. R. (under revision). Individual Differences in Resting-State Brain Rhythms Uniquely Predict Second Language Learning Rate and Speaking Accuracy in Adult Learners. Journal of Cognitive Neuroscience.
- a. Individual Differences in Resting-State Brain Rhythms Uniquely Predict Second Language Learning Rate and Speaking Accuracy in Adult Learners.
  - b. Journal of Cognitive Neuroscience
  - c. Chantel S Prat, Brianna L Yamasaki, Erica R Peterson
  - d. language aptitude, qEEG, resting-state networks, right hemisphere
  - e. Approved for public release: Distribution Unlimited
  - f. Under Review
  - g. NA
  - h. NA
  - i. NA
  - j. NA
  - k. NA
  - l. NA
  - m. NA
  - n. Yes
  - o. Yes
6. 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 computational model. *Cognition*, 164, 31-45.

- a. Individual differences in the Simon effect are underpinned by differences in the competitive dynamics in the basal ganglia: An experimental verification and a computational 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, computational modeling
  - e. Approved for public release: distribution unlimited.
  - f. Published
  - g. DOI
  - h. 10.1016/j.cognition.2017.03.001
  - i. July 2017
  - j. 164
  - k. July
  - l. 31
  - m. Amsterdam, Netherlands
  - n. Yes
  - o. Yes
7. Stocco, A. (2017). An integrated computational framework for attention, reinforcement learning, and working memory. *The 2017 AAAI Fall Symposium Series*. pp. 470-475. AAAI Press, Palo Alto, California.
- a. An integrated computational framework for attention, reinforcement learning, and working memory.
  - b. *The 2017 AAAI Fall Symposium Series*
  - c. Andrea Stocco
  - d. cognitive modeling; executive function; selective attention; reinforcement learning; decision making
  - e. Approved for public release: Distribution Unlimited
  - f. Published
  - g. Other
  - h. NA
  - i. 2017
  - j. NA
  - k. NA
  - l. 470
  - m. Palo Alto, California
  - n. Yes
  - o. Yes
  - p.
8. Becker, T. M., Prat, C. S., & Stocco, A. (2016). A network-level analysis of cognitive flexibility reveals a differential influence of the anterior cingulate cortex in bilinguals versus monolinguals. *Neuropsychologia*, 85, 62-73.
- a. A network-level analysis of cognitive flexibility reveals a differential influence of

the anterior cingulate cortex in bilinguals versus monolinguals

- b. Neuropsychologia
- c. Theresa M. Becker, Chantel S. Prat, Andrea Stocco
- d. Bilingualism, Dynamic Causal Modeling, Effective connectivity, Executive functioning, fMRI
- e. Approved for public release: distribution unlimited.
- f. Published
- g. ISSN
- h. 0028-3932
- i. May 2016
- j. 85
- k. NA
- l. 62
- m. Amsterdam, Netherlands
- n. No
- o. Yes

9. Prat, C. S., Yamasaki, B. L., Kluender, R. A., & Stocco, A. (2016). Resting-State EEG Predicts Rate of Second Language Learning in Adults. *Brain and language*, 157, 44-50.

- a. Resting-state qEEG predicts rate of second language learning in adults
- b. Brain & Language
- c. Chantel S. Prat, Brianna L. Yamasaki, Reina A. Kluender, Andrea Stocco
- d. Second language aptitude, Second language acquisition, EEG, Neuroplasticity, Individual differences, Bilingualism, Working memory capacity
- e. Approved for public release: distribution unlimited.
- f. Published
- g. ISSN
- h. 0093-934X
- i. July 2016
- j. 157
- k. NA
- l. 44
- m. Amsterdam, Netherlands
- n. Yes
- o. Yes

10. Yamasaki, B. L., Stocco, A., & Prat, C. S. (revision under review). Relating Individual Differences in Bilingual Language Profiles to Executive Attention. *Language, Cognition, and Neuroscience*.

- a. Relating Individual Differences in Bilingual Language Experiences to Executive Attention
- b. Language, Cognition, and Neuroscience.

- c. Brianna Yamasaki, Andrea Stocco, Chantel Prat
  - d. Bilingualism, Executive Attention, Language Use, Basal Ganglia Functioning, Attentional Blink
  - e. Approved for public release: distribution unlimited.
  - f. Submitted
  - g. ISSN
  - h. 0749-596X
  - i. NA
  - j. NA
  - k. NA
  - l. NA
  - m. NA
  - n. Yes
  - o. Yes
11. Ceballos, J. M., Stocco, A., Yamasaki, B. L., Becker, T. M., & Prat, C. S. (submitted). How does preparation influence cognitive control? Informative cues guide attentional and cognitive control neural systems for conflict resolution. *Neuroimage*.
- a. How does preparation influence cognitive control? Informative cues guide attentional and cognitive control neural systems for conflict resolution.
  - b. NeuroImage
  - c. Jose Ceballos, Andrea Stocco, Brianna Yamasaki, Theresa Becker
  - d. cognitive control, conflict resolution, response inhibition, preparation, cuing, basal ganglia
  - e. Approved for public release: distribution unlimited.
  - f. Submitted
  - g. ISSN
  - h. 1053-8119
  - i. NA
  - j. NA
  - k. NA
  - l. NA
  - m. NA
  - n. Yes
  - o. Yes

Conference Papers:

- 1. Rice, P. J., & Stocco, A. (2017). Basal ganglia-inspired functional constraints improve the robustness of Q-value estimates in model-free reinforcement learning. *Proceedings of the 15h International Conference on Cognitive Modeling*.

- a. Basal ganglia-inspired functional constraints improve the robustness of Q-value estimates in model-free reinforcement learning
- b. International Conference on Cognitive Modeling
- c. July 22-25 2017
- d. University of Warwick, UK
- e. Published
- f. 2017
- g. NA
- h. NA
- i. Yes

Posters:

1. Yamasaki, B. L., Ceballos, J. M., & Prat, C. S. (2017). The Role of Basal Ganglia Filtering Mechanisms in Second Language Aptitude. Poster presentation given at the 9th Annual Meeting of the Society for the Neurobiology of Language, Baltimore, Maryland.
  - a. The Role of Basal Ganglia Filtering Mechanisms in Second Language Aptitude
  - b. Brianna L Yamasaki, Jose M Ceballos, Chantel S Prat
  - c. Society for the Neurobiology of Language
  - d. Nov 11-15, 2017
  - e. Baltimore, Maryland
  - f. Other
  - g. 2017
  - h. NA
  - i. NA
  - j. Yes
2. Ceballos, J. M., Yamasaki, B. L., & Prat, C. S. (2017). Context-dependent Filtering in the Caudate Nucleus of the Basal Ganglia as a Predictor of Second-Language Learning Aptitude. Poster presentation given at the 9th Annual Meeting of the Society for the Neurobiology of Language, Baltimore, Maryland.
  - a. Context-dependent Filtering in the Caudate Nucleus of the Basal Ganglia as a Predictor of Second-Language Learning Aptitude
  - b. Jose M Ceballos, Brianna L Yamasaki, Chantel S Prat
  - c. Society for the Neurobiology of Language
  - d. Nov 11-15, 2017
  - e. Baltimore, Maryland
  - f. Other
  - g. 2017
  - h. NA
  - i. NA
  - j. Yes
3. Seo, R., Ceballos, J. M., Yamasaki, B. L., & Prat, C. S. (2017). A Dynamic Causal Modeling Analysis of the Role of the Caudate Nucleus and Prefrontal Cortex in Bilingual Language

Control. Poster presentation given at the 9th Annual Meeting of the Society for the Neurobiology of Language, Baltimore, Maryland.

- a. A Dynamic Causal Modeling Analysis of the Role of the Caudate Nucleus and Prefrontal Cortex in Bilingual Language Control.
  - b. Roy Seo, Jose M Ceballos, Brianna L Yamasaki, Chantel S Prat
  - c. Society for the Neurobiology of Language
  - d. Nov 11-15, 2017
  - e. Baltimore, Maryland
  - f. Other
  - g. 2017
  - h. NA
  - i. NA
  - j. Yes
4. Yamasaki, B. L. & Prat, C. S. (2017). Understanding the Nature of Cross-Linguistic Interference and its Importance for Second-Language Reading Skill. Poster presentation given at the 27th Annual Meeting of the Society for Text and Discourse, Philadelphia, Pennsylvania.
- a. Understanding the Nature of Cross-Linguistic Interference and its Importance for Second-Language Reading Skill.
  - b. Brianna L Yamasaki, Chantel S Prat
  - c. Society for Text and Discourse
  - d. July 31 – August 2, 2017
  - e. Philadelphia, Pennsylvania
  - f. Other
  - g. 2017
  - h. NA
  - i. NA
  - j. Yes
5. Prat, C. S. & Yamasaki, B. L., (2017). A Neural Information Processing Account of Individual Differences in Reading Skill. Spoken Presentation given at the Society for Text and Discourse annual conference, Philadelphia, PA.
- a. A Neural Information Processing Account of Individual Differences in Reading Skill.
  - b. Chantel S Prat, Brianna L Yamasaki
  - c. Society for Text and Discourse
  - d. July 31 – August 2, 2017
  - e. Philadelphia, Pennsylvania
  - f. Other
  - g. 2017
  - h. NA
  - i. NA
  - j. Yes

6. Seo, R., Ceballos, J. M., & Prat, C. S. (2017) A DCM Analysis: Role of the Caudate Nucleus and Prefrontal Cortex in Bilingual Language Control. Poster Presentation at the Society for the Neurobiology of Language, Baltimore, MD.
  - a. A DCM Analysis: Role of the Caudate Nucleus and Prefrontal Cortex in Bilingual Language Control
  - b. Roy Seo, Jose M Ceballos, Chantel S Prat
  - c. Society for the Neurobiology of Language
  - d. November 8-10, 2017
  - e. Baltimore, Maryland
  - f. Other
  - g. 2017
  - h. NA
  - i. NA
  - j. Yes
7. Seo, R. (2016). Dissociable roles of the anterior cingulate cortex, basal ganglia, and dorsolateral prefrontal cortex in bilingual language control. Presented at Korean BioMedical Scientists Annual Conference, Seattle WA, USA
  - a. Dissociable roles of the anterior cingulate cortex, basal ganglia, and dorsolateral prefrontal cortex in bilingual language control
  - b. Roy Seo
  - c. Korean BioMedical Scientists Annual Conference
  - d. Dec 16, 2016
  - e. Seattle, Washington
  - f. Other
  - g. 2016
  - h. NA
  - i. NA
  - j. Yes
8. Yamasaki, B. L. & Prat, C. S. (2016). *Neural Adaptability and Individual Differences in Native and Second-Language English Readers*. Oral presentation given at the 26<sup>th</sup> Annual Meeting of the Society for Text and Discourse, Kassel, Germany.
  - a. Neural Adaptability and Individual Differences in Native and Second-Language English Readers
  - b. Brianna L Yamsaki, Chantel S Prat
  - c. Society for Text and Discourse
  - d. July 18-20, 2016
  - e. Kassel, Germany
  - f. Other
  - g. 2016
  - h. NA
  - i. NA
  - j. Yes

9. Ceballos, J. M., Stocco, A., Becker, T., Yamasaki, B. L., & Prat, C.S. (2015). *The Cognitive Neuroscience of Preparatory Processes: Isolating the "Execute" From Executive Functions*. Poster presentation given at Organization for Human Brain Mapping, Honolulu, Hawaii.
  - a. The Cognitive Neuroscience of Preparatory Processes: Isolating the "Execute" From Executive Functions
  - b. Jose M Ceballos, Theresa Becker, Brianna L Yamasaki
  - c. International Conference for the Organization of Human Brain Mapping
  - d. June 14-18, 2015
  - e. Honolulu, Hawaii
  - f. Other
  - g. 2015
  - h. NA
  - i. NA
  - j. Yes
10. Prat CS, Yamasaki BL, and Stocco A. 2015. Measuring changes in brain and behavior following second language training. International Conference for the Organization of Human Brain Mapping; June 14-18; Honolulu, HI, USA.
  - a. Measuring changes in brain and behavior following second language training
  - b. Chantel S Prat, Brianna L Yamasaki, Andrea Stocco
  - c. International Conference for the Organization of Human Brain Mapping
  - d. June 14-18, 2015
  - e. Honolulu, Hawaii
  - f. Other
  - g. 2015
  - h. NA
  - i. NA
  - j. Yes
11. Prat CS, Yamasaki BL, Ceballos JM and Seo R. 2015. Relating the demands of bilingual language control to inhibition: An individual difference approach. Bilingualism and Executive Functioning Workshop; May 4-6; New York, NY, USA.
  - a. Relating the demands of bilingual language control to inhibition: An individual difference approach.
  - b. Chantel S Prat, Brianna L Yamasaki, Jose M Ceballos, Roy Seo
  - c. Bilingualism and Executive Functioning Workshop
  - d. May 4-6, 2015
  - e. New York, New York
  - f. Other
  - g. 2015
  - h. NA
  - i. NA
  - j. Yes
12. Seo, R., Stocco, A., & Prat, C.S. (2015). Decomposing the bilingual language control network into preparatory process and execution. Presented at Society for Neuroscience,

Chicago, IL

- a. Decomposing the bilingual language control network into preparatory process and execution.
- b. Roy Seo, Chantel Prat
- c. Society for Neuroscience
- d. October 17-21, 2015
- e. Chicago, IL
- f. Other
- g. October 17
- h. NA
- i. NA
- j. Yes

13. Kelley, J. (2016, May). *Investigating Speed-Accuracy Trade-Offs as a Mediating Factor Between Inhibitory Control and Impulsivity Measures*. Poster session presented at the UW psychology honors symposium, Seattle, WA.

- a. Investigating Speed-Accuracy Trade-Offs as a Mediating Factor Between Inhibitory Control and Impulsivity Measures
- b. James Kelley
- c. UW psychology honors symposium
- d. Conference Date
- e. Seattle, WA
- f. Other
- g. May 2016
- h. NA
- i. NA
- j. Yes

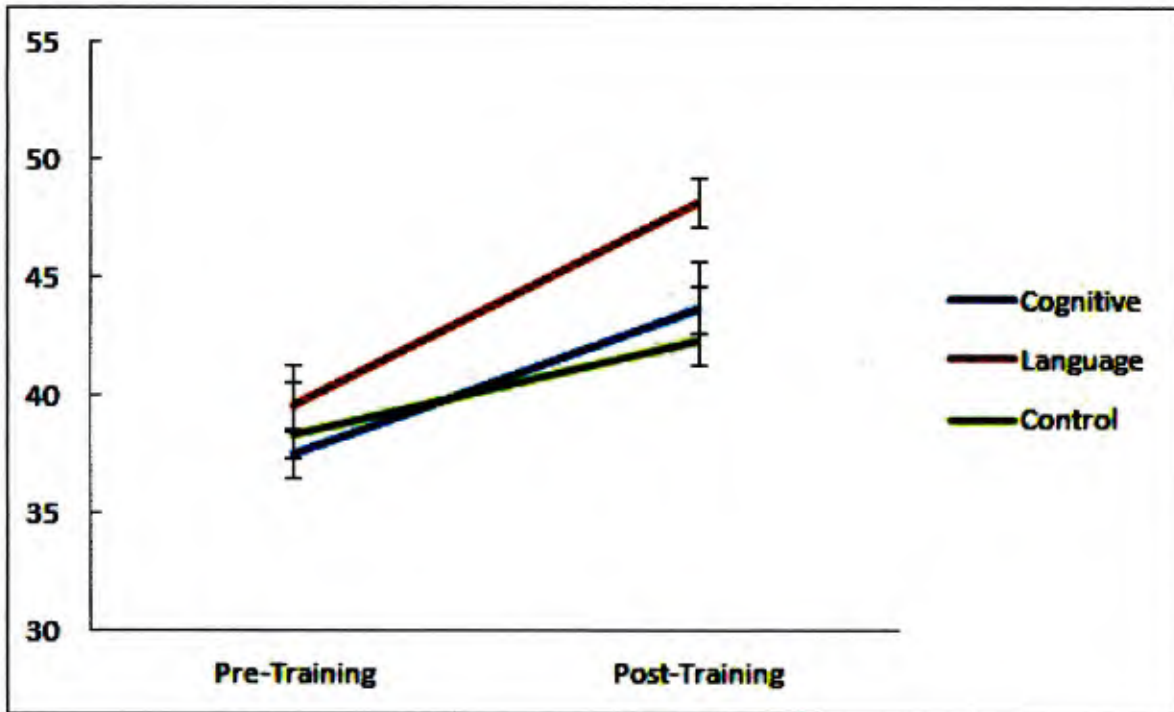
14. Yamasaki, B. L. & Prat, C. S. (2015). *Cortical Dynamics and Individual Differences in Reading: Relating Beta Oscillations with Reading Skill*. Oral presentation given at the 25th Annual Meeting of the Society for Text and Discourse, Minneapolis, Minnesota.

- a. Cortical Dynamics and Individual Differences in Reading: Relating Beta Oscillations with Reading Skill
- b. Brianna Yamasaki, Chantel Prat
- c. Society for Text and Discourse
- d. July 6
- e. Minneapolis, Minnesota.
- f. Other
- g. July 7<sup>th</sup>
- h. NA
- i. NA
- j. Yes

15. Renno, T.J., Prat, C.S. (2016, June). *Believing the hype: understanding the role of belief on cognitive performance*. Presented at the University of Washington Psychology Department Honors Students Poster Session, Seattle, WA.
  - a. Believing the hype: understanding the role of belief on cognitive performance.
  - b. Taylor Renno, Chantel Prat
  - c. University of Washington Psychology Department Honors Students Poster Session
  - d. May 31<sup>st</sup>
  - e. Seattle, WA
  - f. Other
  - g. May 31<sup>st</sup>
  - h. NA
  - i. NA
  - j. Yes
16. Pighin, M., & Prat, C. (2016, June). *Improving Executive Attention and Reading Comprehension in Healthy Individuals using Neurofeedback Training*. Poster presented at the Mary Gates Undergraduate Research Symposium, Seattle, WA.
  - a. Improving Executive Attention and Reading Comprehension in Healthy Individuals using Neurofeedback Training.
  - b. Marissa Pighin, Chantel Prat
  - c. Mary Gates Undergraduate Research Symposium
  - d. May 20, 2016
  - e. Seattle, WA
  - f. Other
  - g. May 20
  - h. NA
  - i. NA
  - j. Yes
17. Yamasaki, B. L., Stocco, A., & Prat, C. S. (2014). The Neural Correlates of Individual Differences in Bilingual Language Control. Poster presentation given at the 6th Annual Meeting of the Society for the Neurobiology of Language, Amsterdam, Netherlands.
  - a. The Neural Correlates of Individual Differences in Bilingual Language Control
  - b. Brianna L Yamasaki, Andrea Stocco, Chantel S Prat
  - c. Society for the Neurobiology of Language
  - d. August 27-29, 2014
  - e. Amsterdam, Netherlands
  - f. Other
  - g. 2014
  - h. NA
  - i. NA
  - j. Yes

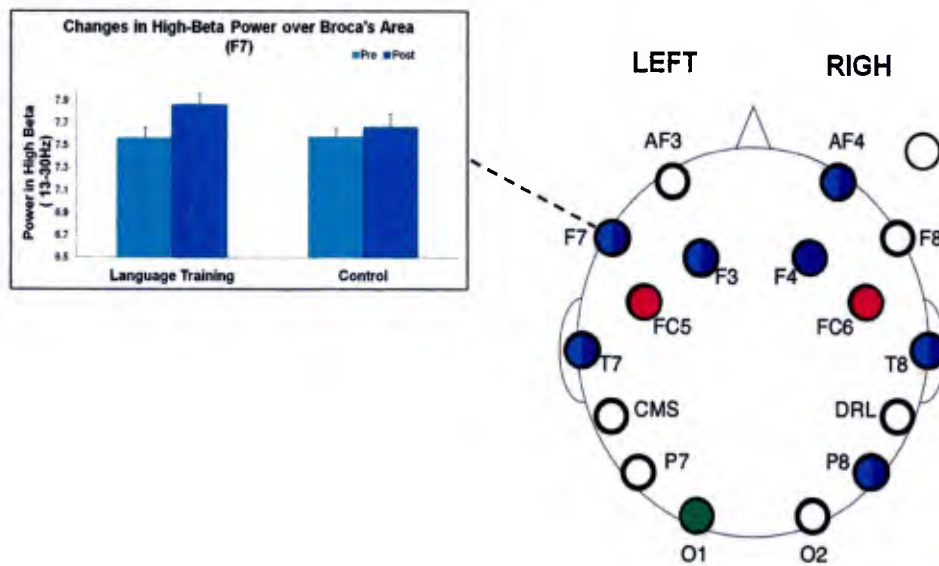
18. Seo, R., Stocco, A., Ceballos, J. M., & Prat, C. S. (2014, August). Linguistic rule representation in the bilingual brain. Poster presented at the annual meeting for the Society for the Neurobiology of Language, Amsterdam, Netherlands.

- k. Linguistic rule representation in the bilingual brain.
- l. Roy Seo, Andrea Stocco, Jose M Ceballos, Chantel S Prat
- m. Society for the Neurobiology of Language
- n. August 27-29, 2014
- o. Amsterdam, Netherlands
- p. Other
- q. 2014
- r. NA
- s. NA
- t. Yes



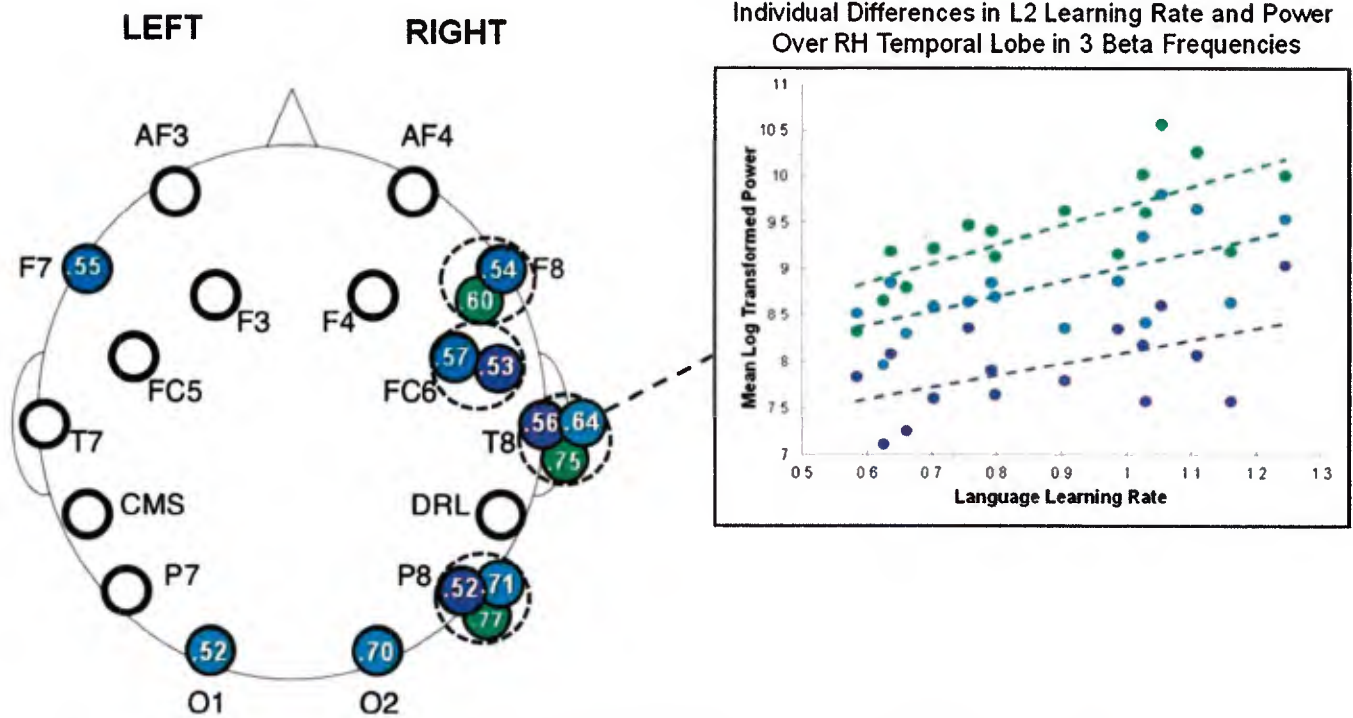
**Figure 1:** Changes in composite working memory span scores as a function of three training conditions.

## Significant Changes in Delta, Alpha, Beta, and Gamma Frequencies following Second Language Training



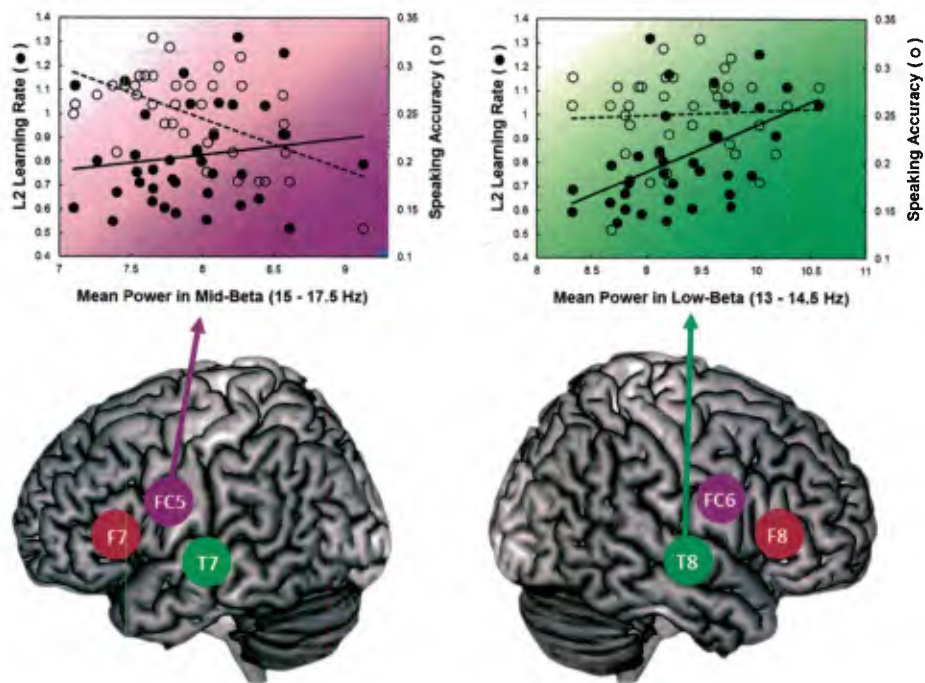
**Figure 2:** Changes in resting-state qEEG power spectra following eight weeks of French language training.

## Predictive Utility of Low, Mid, and High beta Frequency Ranges for Language Learning Rate



**Figure 3:** Resting state qEEG predicts rate of L2 learning (Prat, Yamasaki, Kluender & Stocco, 2016).

## Unique Resting-state qEEG Predictors of L2 Learning Rate● and Speaking Accuracy○



**Figure 4:** Resting state qEEG uniquely predicts rate of L2 learning and speaking accuracy (Prat, Yamasaki & Peterson, under revision).

## Correlations between Structural Properties of the Basal Ganglia and Second Language Learning Rate

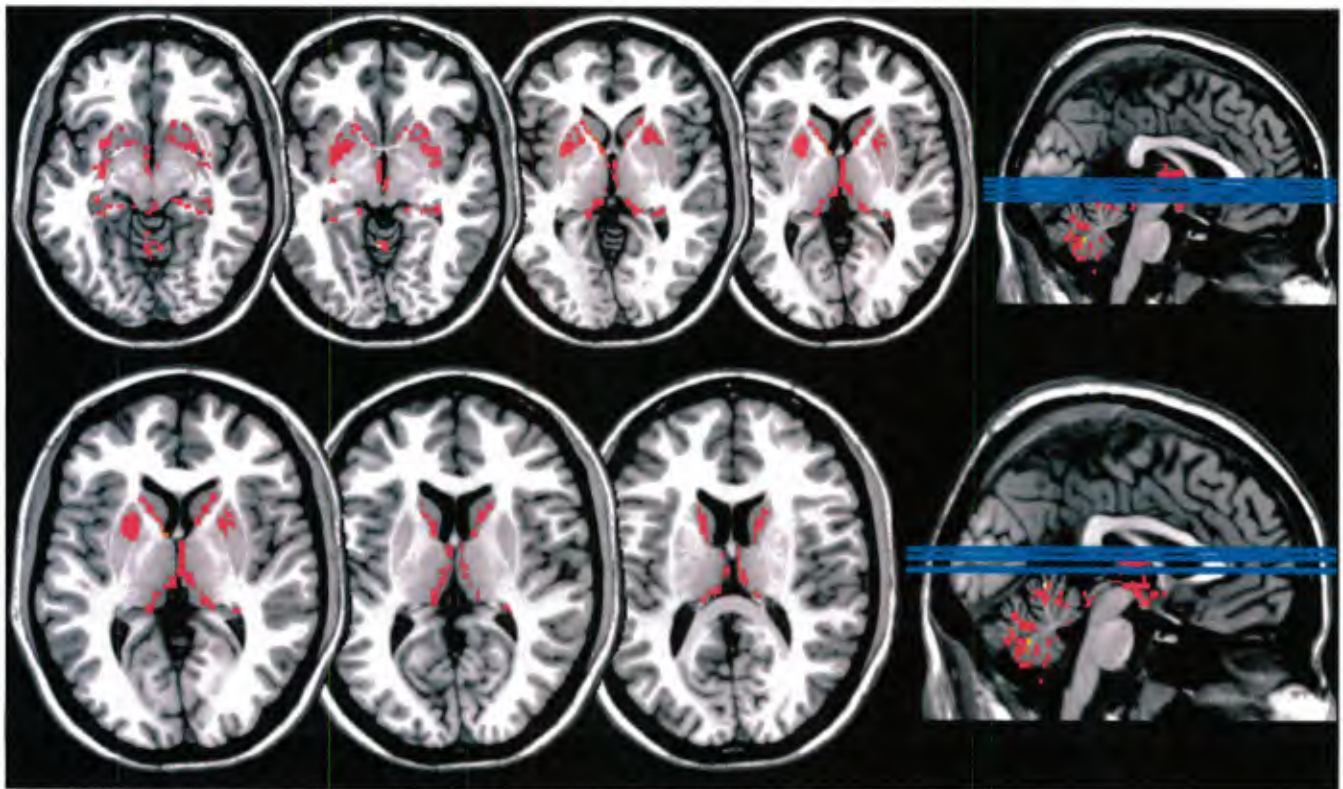
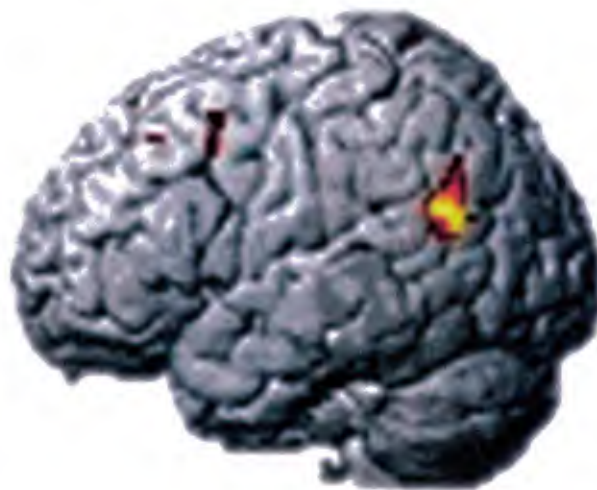
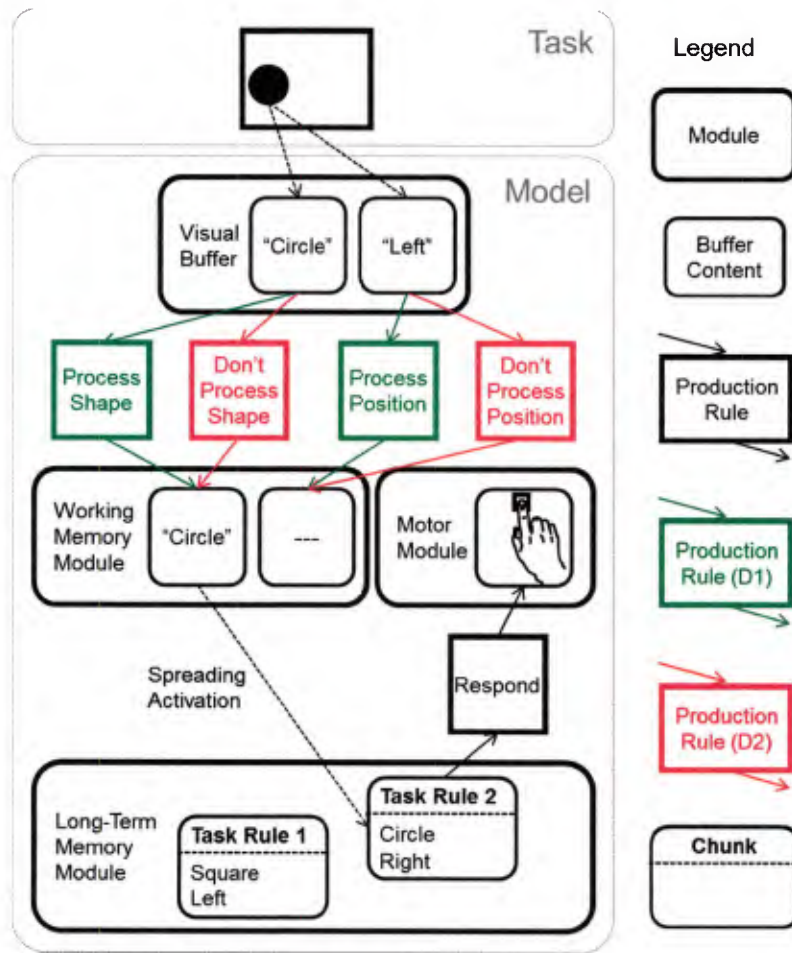


Figure 5: Structural properties of the basal ganglia predict L2 learning rate.

**Correlations between Patterns of Activation for “Filter” vs. “No-filter”  
Working Memory Trials and Subsequent Second Language Learning**

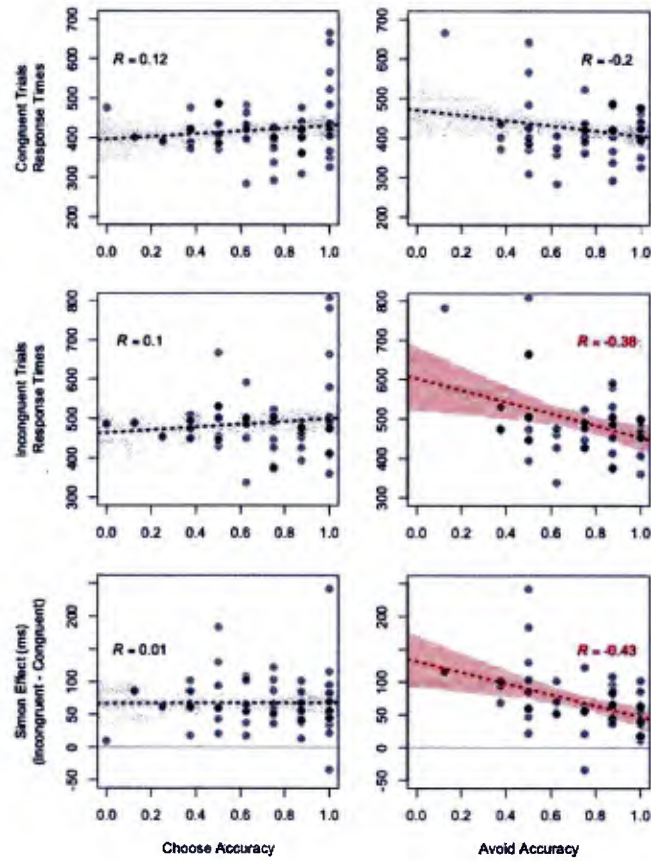


**Figure 6:** Semantic filtering in a working memory task predicts L2 learning accuracy.



**Figure 7:** Model of the Simon task that uses the modified ACT-R architecture that accounts for D1 and D2 pathways in the basal ganglia (green and red rectangles).

Correlations between PSS Task  
and Simon Task



**Figure 8:** Experimental results showing the correlation between sensitivity to unrewarding outcomes (“Avoid accuracy”) correlates with better performance (faster RTs) on the Simon task.