

**Supplementary Information: Detailed Materials Section for
Individual Differences in Resting-State Brain Rhythms Uniquely Predict Second Language
Learning Rate and Willingness to Communicate in Adults**

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Raven's Advanced Progressive Matrices (RAPM). RAPM is a classic test of non-verbal reasoning in which participants are presented with a three by three matrix of black and white shapes with a blank 9th cell in the bottom right hand corner. They are instructed to induce the rules governing the progression of the shapes both horizontally and vertically, and to choose the item that completes the pattern based on these rules. Participants choose from a selection of eight possible answers to finish the matrix. In this experiment a shortened, 18-item version of the original RAPM was used. The short form was created by splitting the original 36-item test into two 18-item versions. Questions were divided into sets of equal rigor using item difficulty norms (1). Participants were given 20 minutes to complete the test, and the total number of correct answers was used as the independent variable.

The Simon Task. The Simon task (2) measures a participant's ability to disregard task-irrelevant information when it competes for attention with task-relevant information. In this task, participants are presented with a series of shapes and are asked to respond with a specific keystroke according to the type of shape presented (e.g., squares require a left-handed key press and circles require a right-handed key press). Unbeknownst to participants, the location of the stimuli on the screen is consistent with the laterality of the required response 75% of the time (congruent trials) and is inconsistent for the remaining 25% of the trials (incongruent trials). To determine performance, response time and accuracy is calculated separately for congruent and incongruent trials, and a difference score is calculated between mean response times (or accuracy) for congruent and incongruent trials.

3-Back Updating Task. The 3-Back task is a particular instantiation of the more general class of N-back tasks, which are computer-based measures of the updating component of working memory (3). In this computer-based task, individual letters are presented serially in the center of the screen. After three initial stimuli, participants must respond according to whether or not the letter currently presented is the same as the letter presented three stimuli ago. This is true in 50% of the trials (match trials). The remaining trials are either completely different from all recent stimuli presented (nonmatch; 25%) or match a stimulus recently presented, but not in the correct position (distractor trials; 25%). Performance was characterized both by the percentage of correct answers across all conditions, and the percentage of correct rejections of the distractor trials specifically.

Color-Shape Switching Task. The Color-Shape Switching Task is a computer-based measure of the ability to switch flexibly between disparate task goals (4). On each trial, one of four possible images that varied in color and shape (blue circles, blue squares, orange circles, and orange squares) appears in one of two possible locations on the screen (top or bottom). Participants are instructed to respond to a particular stimulus feature (color or shape) depending on whether the stimulus appears on the top or bottom of the screen. The particular mapping was counterbalanced across participants. On any given trial, the relevant stimulus feature for the

current trial was either the same as the previous trial (repeat) or it switched (switch trials). Performance was calculated as slower response times, or decreased accuracy, for switch as opposed to repeat trials.

A-X Continuous Performance Test (AXCPT). The AXCPT is a computer-based measure of the ability to maintain a specific task goal (5). In each trial for this computer-based measure, letters are presented one after another in the center of the screen. Participants are instructed to press a “yes” button for every trial in which an X that was preceded by an A is presented. Under all other circumstances, participants respond “no” that the target condition was not met. There are four critical conditions in this task whose probabilities are derived from two-stimulus pairings: (1) X is preceded by A (AX trials; 70% of the trials), (2) X is preceded by a letter other than A (BX trials; 10% of the trials), (3) a letter other than X is preceded by A (AY trials; 10% of the trials), and (4) a letter other than X is preceded by a letter other than A (BY trials; 10% of the trials). Performance on this task is indicated by response time differences between “AY” trials (which should be relatively difficult if one relies on the predictive utility of the “A” cue) to “BX” trials (which should be relatively easy if one recognizes that any trial not following an A can’t be a target). Response times were computed only for conditions in which the participants responded to both the probe and target correctly.

The Probabilistic Stimulus Selection Task of Implicit Learning. The Probabilistic Stimulus Selection Task of Implicit Learning (6) measures whether participants are more sensitive to positive or negative feedback when learning. Participants are shown pairs of non-verbalizable black figures (characters drawn from the Hiragana syllabary), on a white background. Participants are instructed to select which figure is correct with no advance instructions regarding what makes a choice correct or incorrect. Each figure has a different probability of yielding a success. The task is composed of two phases: (1) a training phase in which participants are presented with three specific figure pairs and implicitly trained through feedback to select the most rewarding figure and (2) a test phase in which participants are presented with novel pairings and their sensitivity to positive and negative feedback is tested. The goal of this measure is to determine whether a participant primarily seeks characters that typically return positive results, or avoids characters that typically return negative results (both strategies lead to successful performance on the task). This is determined by calculating the number of times a participant chooses the character with the greatest probability of being correct, and calculating the number of times a participant avoids choosing the character with the least probability of being correct.

Attentional Blink Task. The Attentional Blink task (7, 8) is a rapid serial visual presentation task designed to measure the limits of perceptual attention. In each trial, 18 stimuli are rapidly presented one by one in the center of the screen. Two of the stimuli are numbers, which the participant is instructed to remember, while the rest of the stimuli are letters (distractors). The lag between the presentation of the two target numbers was varied to produce the following conditions: lag 1, in which the numbers were presented 90ms apart (with no intervening distractors); lag 2, in which the numbers were presented 180ms apart (with one intervening distractor); lag 3, in which the numbers were presented 270ms apart (with two intervening distractors); and lag 8, in which the numbers were presented 720ms apart (with seven intervening distractors). Participants typically show decreased accuracy for trials in which the

second target occurs within the “blink window” (100-500ms after the first target). Thus, the four lag conditions were grouped into those that occurred during the “blink window” (Lag 2 and 3) and those that occurs outside of the “blink window” (Lag 1 and 8). To calculate a participant’s “attentional blink,” mean accuracy of second target recall (for trials in which the first target was also recalled correctly) was determined separately for blink window trials and non-blink window trials. Mean accuracies for Lags 2 and 3 were subtracted from Lags 1 and 8 to calculate the size of the attentional blink.

Stop-Signal Response Inhibition Task. The Stop-Signal Response Inhibition Task (9) measures the inhibitory aspect of executive control. Participants are shown a series of individual numbers in the center of the screen and are assigned the task of differentiating between even and odd numbers. However, participants are instructed to refrain from any response when the number presented on the screen turns red (20% of trials). An adaptive process is used to vary the duration between the stimuli appearing on the screen and it subsequently turning red. This duration was varied such that a participant's accuracy for correctly not responding to red trials was maintained at about 50%. Response inhibition was measured by calculating the longest duration after the subject has initiated a response that they were able to inhibit that response.

Complex Working Memory Span Tasks. Two working memory tasks were employed, using the methods outlined in Unsworth, Heitz, Schrock, and Engle (10). In the first measure, Operation Span, participants recall strings of unrelated letters while doing arithmetic problems. Participants practice each phase of the task, before completing several test blocks in which the number of math problem-letter pairs varies between 3-7. The procedures for the second working memory task, the Reading Span task, are nearly identical in presentation to Operation Span, except that in between letters, participants are asked to read sentences and determine whether or not the sentences make sense. Working memory capacity for both tasks were calculated by summing all correct answers from perfectly recalled sets of trials.

Nelson-Denny Reading Test of L1 Proficiency. The Nelson-Denny Reading Test (11) is a pencil-and-paper standardized test of English reading comprehension normed for college students. It contains 38 multiple-choice reading comprehension questions referencing a selection of 8 reading passages. Participants are given 20 minutes to complete the test. Absolute scores are used to generate percentile scores for each participant to rate his or her reading comprehension ability. Norms used to create percentile scores were values for a sophomore level college student regardless of each participant’s college level because this allowed reading comprehension abilities to be compared across the sample of participants in the study.

Language Training Software. The OLCTS (12), a virtual immersion language training program, was used to provide participants with eight weeks of French language training. The OLCTS provides immersive, goal-directed cultural and language training including comprehension and production components (with speech recognition software), as well as socio-cultural practices and pragmatic instruction. These skills are applied through goal-directed virtual reality scenarios through interactions with avatars, and then tested explicitly through quizzes that incorporate all aspects of linguistic proficiency (written comprehension, verbal production, and auditory comprehension). The OLCTS is organized by “units” or “levels.” Each level ends with a quiz. In the current experiment, we did not allow participants to advance to another level until

they passed the quiz with a minimum accuracy of 50%. At the end of each 30-minute training session, each participant's level was recorded. Across training sessions, a regression line was fit to this level information was used to calculate a **rate of L2 learning** variable.

Additionally, the OLCTS requires participants to produce speech utterances of varying length and complexity. During these productions, the software records both the number of total speech attempts as well as the number of correct speech attempts. A speech attempt is considered correct when the utterance is recognized, with the highest likelihood of recognition, from a classification model that uses utterances of both native speakers and of learners in the "correct" model and also includes a "garbage" parameter. Speaking accuracy was determined by taking the ratio of correct speech attempts to total speech attempts as detected by the software.

The French-English Translation Posttest of French Proficiency. Long-term declarative memory for items studied were assessed using a French-English translation test, which was created individually for each participant based on the materials he or she encountered over the eight-week session of language training. The test required participants to indicate the correct English translation for 50 French words or phrases they learned during training. The number of items drawn from each level were proportionate to the amount of material covered on that level.

References for Supplementary Information

1. Arthur W, Day D (1994) Development of a short form for the Raven's Advanced Progressive Matrices Test. *Educ Psychol Meas* 54(2): 394-403.
2. Stocco A et al (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.
3. Kane M, Conway A, Miura T, Colflesh G (2007) Working memory, attention control, and the N-back task: a question of construct validity. *J Exp Psychol Learn Mem Cogn* 33(3): 615.
4. Monsell S (2003) Task switching. *Trends Cogn Sci* 7(3): 134-140
5. Cohen J, Barch D, Carter C, Servan-Schreiber D (1999) Context-processing deficits in schizophrenia: Converging evidence from three theoretically motivated cognitive tasks. *J Abnorm Psychol* 108(1): 120-133.
6. Frank M, Seeberger L, O'Reilly R (2004) By carrot or by stick: Cognitive reinforcement learning in parkinsonism. *Science* 306 (5703): 1940-1943.
7. Broadbent D, Broadbent M (1987) From detection to identification: Response to multiple targets in rapid serial visual presentation. *Perception & Psychophysics* 42(2): 105-113.
8. Raymond J, Shapiro K, Arnell K (1992) Temporary suppression of visual processing in an RSVP task: An attentional blink? *J Exp Psychol Hum Percept Perform* 18(3): 849-860.
9. Logan G (1994) On the ability to inhibit thought and action: A users' guide to the stop signal paradigm. *Inhibitory Processes in Attention, Memory, and Language*, eds Dagenbach D, Carr T (Academic Press, San Diego, Ca.), pp 189-239.
10. Unsworth N, Heitz R, Schrock J, Engle R (2005) An automated version of the operation span task. *Behav Res Methods* 37(3): 498-505.
11. Brown J, Fishco V, Hanna G (1993) *Nelson-denny reading test: Manual for scoring and interpretation forms G & H*. (Riverside Publishing, Rolling Meadows, Il.).
12. Johnson W, Friedland L, Watson A, Surface E (2012) The art and science of developing intercultural competence. *Adaptive Technologies for Training and Education*, eds Durlach P, Lesgold A (Cambridge University Press, New York, Ny.), pp 261-286.