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Title: Measuring Statistical Learning Across Modalities and Domains in School-Aged Children Via an Online Platform and Neuroimaging Techniques

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Author Questionnaire

1. Microscopy: Does your protocol involve video microscopy, such as filming a complex dissection or microinjection technique? **N**

2. Software: Does the part of your protocol being filmed demonstrate software usage? **Y**

3. Filming location: Will the filming need to take place in multiple locations (greater than walking distance)? **N**

Protocol Length
Number of Shots: **49**

Introduction

1. Introductory Interview Statements

REQUIRED:

1.1. **Zhenghan Qi**: The ability to extract patterns from inputs is foundational for language and cognitive development. This technique can address whether the remarkable heterogeneity of statistical learning in children is explained by domain-general or domain-specific mechanisms **[1]**.

> 1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

REQUIRED:

1.2. **Julie M. Schneider**: Our protocol facilitates the measurement of statistical learning across domains and modalities within individuals, is child friendly, and combines web-based behavioral and lab-based neuroimaging techniques **[1]**.

> 1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

OPTIONAL:

1.3. **Zhenghan Qi**: This method will provide insight into the learning frameworks of language development. If applied in special populations, our protocol may also advance our understanding of language learning difficulties **[1]**.

> 1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera *Videographer: Can cut for time*

OPTIONAL:

1.4. **Julie M. Schneider**: We are in the process of making our tasks accessible to the research community on Zenodo and Github. We advise other groups to reproduce our tasks as they become available **[1]**.

> 1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera *Videographer: Can cut for time*

Ethics Title Card

1.5.   Procedures involving human subjects have been approved by the Institutional Review Board (IRB) at The University of Delaware.

Protocol

2. Web-Based Protocol

2.1.   To perform a web-based protocol, first navigate to the web-based statistical learning paradigm **[1-TXT]**.

    2.1.1.   WIDE: Participant accessing website, with monitor visible in frame **TEXT: https://www.cogscigame.co**

2.2.   For the syllable task, introduce the Participant to an alien and its favorite word in its alien language **[1-TXT][2]**.

    2.2.1.   ~~Talent indicating alien on screen to Participant~~ ~~**TEXT: Task order randomized for every participant**~~ NOTE: Filmed but please cut as the screenshot best demonstrates this step

    2.2.2.   SCREEN: 2.2.2. *Video Editor: please show file and include "favorite word" audio after voiceover narrative*

2.3.   Inform the Participant that they will listen to the alien's language **[1]** and to remember to press the spacebar whenever they hear the favorite word **[2]**.

    2.3.1.   ~~Talent instructing Participant/gesturing to screen~~ NOTE: Filmed but please cut as the screenshot best demonstrates this step

    2.3.2.   SCREEN: 2.3.2.

2.4.   Have the Participant complete a practice trial before the familiarization phase, in which they must press the space bar as soon as the alien's favorite word is heard **[1-TXT]**.

    2.4.1.   Participant watching screen and pressing space bar as necessary, with monitor visible in frame **TEXT: Do not provide explicit instructions about triplets**

2.5.   During the test phase, instruct the Participant to select one of the two sequences that sound more familiar **[1-TXT]**.

    2.5.1.   Participant watching screen and pressing button left or right arrow to choose the triplet, with monitor visible in frame **TEXT: Each trial must end with response**

2.6.   The target sequence will be presented in the familiarization phase **[1][2]**. The foil sequence will have not been previously presented **[3][4]**.

2.6.1. Participant listening to target sequence, with monitor visible in frame *Videographer: please include enough footage of Talent at monitor to allow target sequence to be played at end of voiceover narrative*

2.6.2. SCREEN: 2.6.1. *Video Editor: please play audio at end of 2.6.1. voiceover narration*

2.6.3. Participant listening to foil sequence <mark>NOTE: Take 4 has pause before action for VO, if needed</mark> *Videographer: please include enough footage of Talent at monitor to allow target sequence to be played at end of voiceover narrative*

2.6.4. SCREEN: 2.6.2. *Video Editor: please play audio at end of 2.6.3. voiceover narration*

2.7. In the tone task, inform the Participant that they will have to keep track of the alien's favorite note in its folk song **[1]**. The test phase will follow the same design as the syllable task **[2][3]**.

2.7.1. SCREEN: 2.7.1. *Video Editor: please show file and include "favorite note" audio after voiceover narrative*

2.7.2. Participant at computer, listening to song <mark>NOTE: Take 3 has pause before action for VO, if needed</mark> *Videographer: please include enough footage of Talent at monitor to allow target sequence to be played at end of voiceover narrative*

2.7.3. SCREEN: 2.7.2. *Video Editor: please play audio at end of 2.7.2. voiceover narration*

2.8. In the image task, inform the Participant that they will have to keep track of a special alien **[1]** as a group of aliens line up to enter a spaceship **[2]**.

2.8.1. SCREEN: 2.8.1.
2.8.2. SCREEN: 2.8.2.

2.9. During the test phase, present both targets in the familiarization phase and foil triplets not seen before to the Participant in pairs **[2]**.

2.9.1. Participant watching screen and pressing button 1 or 2 to choose the target triplet, with monitor visible in frame *Videographer: please include enough footage of Talent at monitor to allow target sequence to be played at end of voiceover narrative/Video Editor: please include target sequence sounds*

2.10. In the letter task, inform the Participant that they will have to keep track of the alien's favorite sign as the alien holds up signs for a parade **[1-TXT]**.

2.10.1. SCREEN: 2.10.1. **TEXT: Test phase follows same design as image task**

3. Task-Based Functional Magnetic Resonance Imaging (fMRI) Preparation

    3.1.   To help Participants, especially children, become comfortable in the scanner, practice the MRI scanning session with a mock scanner **[1]**.

        3.1.1. WIDE: Talent approaching scanner

    3.2.   Introduce the Participant to the mock scanner, or brain camera **[1]**, and to their "scan-buddy" **[2]**.

        3.2.1. Talent showing Participant scanner
        3.2.2. Talent showing Participant scan buddy

    3.3.   Explain that the purpose of the scan buddy is to keep them company and to help them if they need anything **[1]**.

        3.3.1. Talent showing that the buddy will be with Participant when they go into the scanner

    3.4.   The scan buddy will also gently remind the Participant to keep still if too much motion is detected by the "camera" **[1]**.

        3.4.1. Scan buddy mock reminding Participant to keep still *Videographer: please include enough footage of Participant with scan buddy to allow "keep still reminder" to be played at end of voiceover narrative if appropriate/Video Editor: please include "keep still" audio if appropriate*

    3.5.   Introduce the Participant to the statistical learning paradigm **[1]** and have them complete a brief portion of the task on a computer **[2]**.

        3.5.1. Talent introducing Participant to paradigm, with monitor visible in frame NOTE: Use take 2 *Videographer: Difficult step*
        3.5.2. Participant completing task, with monitor visible in frame NOTE: Use take 2 *Videographer: Difficult step*

    3.6.   After completing the task, help the Participant into the mock scanner **[1]** and play child-friendly videos to help them acclimate to the sound and video **[2]**.

        3.6.1. Participant being placed into scanner *Videographer: Important step*
        3.6.2. Talent at mock scanner, starting "child-friendly" video, with monitor visible in frame NOTE: Use take 3

    3.7.   When the Participant is ready, play a few pre-recorded scanner sound clips to prepare

them for the noises produced by the real MRI … **[1]**.

3.7.1. Talent playing sound clip NOTE: Accompanying audio files available *Videographer/Video Editor: please include brief audio of sound clips at end of narration*

3.8. During this time, have the Participant practice staying still and working with the scan buddy **[1]**.

3.8.1. Shot of Participant still in scan tube with buddy

4. **Task-Based Functional Magnetic Resonance Imaging (fMRI) Protocol**

4.1. When the Participant is comfortable with the mock scanner, confirm that the fMRI (F-M-R-I) data collection protocol is appropriately set up on the MRI acquisition computer **[1]**.

4.1.1. WIDE: Talent checking protocol, with monitor visible in frame

4.2. Have the Participant lie comfortably on the bed of the MRI scanner **[1]** with headphones that protect their ears from the scanner noise **[2]** and a response pad in their hand **[3-TXT]**.

4.2.1. Participant sitting on scanner bed
4.2.2. Talent giving headphones to Participant NOTE: Only one take called take 2
4.2.3. Talent giving response pad to Participant NOTE: Use take 3 **TEXT: Give pad before test to counterbalance whether left or right hand used across Participants**

4.3. Place additional padding around the Participant's head to ensure limited head motion during the data collection **[1]** and give the Participant the option of a scan buddy **[2]**.

4.3.1. Talent placing padding NOTE: Use take 2
4.3.2. Talent offering buddy

4.4. Give the Participant a squeeze ball to use to notify if they are distressed or need to stop **[1]** and place the head coil over the Participant's head **[2]**.

4.4.1. Talent giving Participant a squeeze ball
4.4.2. Talent placing coil

4.5. After aligning the Participant in the scanning bed **[1]**, register a new participant in the acquisition computer, and choose the correct scanning protocol **[2]**.

4.5.1. Participant closing eyes for alignment while talent aligns head

4.5.2. Talent registering participant, with monitor visible in frame

4.6. Insert the scanning bed and Participant into the bore of the MRI **[1]** and show a movie to the Participant while acquiring a structural MRI scan **[2]**.

4.6.1. Bed being inserted into bore

4.6.2. Talent starting movie/at scanner, acquiring scan NOTE: Combine take 1 and take 3

4.7. To have the Participant perform an auditory task, use an intercom system connected to their headphones to inform the Participant that **[1]** "Now we're going to play a button-pressing game. You will hear the aliens say words and play music. Remember to press the button on the response pad whenever you hear the sound you are listening for. There will be 4 parts and each part will last about 5 minutes **[2]**."

4.7.1. Talent turning on microphone or similar

4.7.2. Talent at intercom, speaking text between quotes NOTE: Use take 3. *Videographer/Video Editor: please include audio*

4.8. After giving the instructions, start the paradigm on the presentation computer to allow the acquisition of the auditory statistical learning data **[2]**.

4.8.1. SCREEN: 4.8.1.

4.9. For a visual task, inform the Participant **[1]**, "Now you are going to see the pictures of the aliens and the letters. Whenever you see the picture you are looking for, press the button on your response pad. You will play this game 4 times in a row. It will take about 5 minutes each time **[2]**."

4.9.1. Talent selecting visual task on presentation computer, with monitor visible in frame NOTE: Shot out of sequence, happens after 4.9.2 according to videographer. Author did not leave any notes here.

4.9.2. Talent at intercom, speaking text between quotes NOTE: Also includes audio and shot out of order after 4.7.2 *Videographer/Video Editor: please include audio*

4.10. After giving the instructions, start the paradigm on the presentation computer to acquire the visual statistical learning data **[1]**.

4.10.1. SCREEN: 4.10.1.

4.11. Once the participant has completed the paradigm, stop the MRI **[1]**, safely remove the

Participant from inside the scanner **[2]**, and remove the head coil **[3-TXT]**.

4.11.1. Talent stopping MRI, with monitor visible in frame Author NOTE: We recorded this scene, which does not have apparent action of "stopping", because the protocol automatically ends itself. It is fine to show the monitor for a second before 4.11.2.

4.11.2. Participant being removed from scanner *Videographer: Important step*

4.11.3. Talent removing coil *Videographer: Important step* **TEXT: Transfer MRI data to secure server for analysis**

Protocol Script Questions

A. Which steps from the protocol are the most important for viewers to see?

3.6., 4.7

B. What is the single most difficult aspect of this procedure and what do you do to ensure success?

2.6., 3.5. Ensuring participants understand the task

Results

5. **Results: Representative Statistical Learning Across Modalities and Domains in School-Aged Children**

    5.1. In the web-based statistical learning task **[1]**, children performed significantly better than a 0.5 chance-level on all conditions **[2]**, indicating successful statistical learning at the group level **[3]**.

        5.1.1. LAB MEDIA: Figure 3
        5.1.2. LAB MEDIA: Figure 3 *Video Editor: please emphasize red 0.50 line and/or portions of data bars above red line*
        5.1.3. LAB MEDIA: Figure 3 *Video Editor: please add/emphasize asterisks*

    5.2. The mean reaction time slope **[1]** was negative and significantly below 0 in the syllable condition **[2]** and marginally significant in the letter condition **[3]**, suggesting a faster acceleration of the target detection during the familiarization phase in the linguistic tasks **[4]**.

        5.2.1. LAB MEDIA: Figure 4
        5.2.2. LAB MEDIA: Figure 4 *Video Editor: please emphasize Syllable data bar*
        5.2.3. LAB MEDIA: Figure 4 *Video Editor: please emphasize Letter data bar*
        5.2.4. LAB MEDIA: Figure 4

    5.3. The mean reaction time slope was not significantly different **[1]** from zero in the image or the tone condition **[2]**, despite evidence of learning in the offline measures of accuracy **[3]**.

        5.3.1. LAB MEDIA: Figure 4 *Video Editor: please emphasize Image data bar*
        5.3.2. LAB MEDIA: Figure 4 *Video Editor: please emphasize Tone data points*
        5.3.3. LAB MEDIA: Figure 4

    5.4. Here preliminary fMRI results based on data from 9 developing school-aged children who completed auditory and visual statistical learning tasks are shown **[1]**.

        5.4.1. LAB MEDIA: Figure 6

    5.5. When comparing structured blocks to random blocks, significant clusters were observed across a variety of brain regions depending on the stimulus type **[1]**. These results suggest that the current task design is sensitive to detecting learning-induced hemodynamic changes in children's brain **[2]**.

      5.5.1.   LAB MEDIA: Figure 6 *Video Editor: please emphasize red and/or yellow signals in images*

      5.5.2.   LAB MEDIA: Figure 6

5.6.   Representative findings in adults **[1]** indicate that the structured sequences are learnable **[2]**, supported by a significantly quicker response time in the structured condition compared to the random condition in all of the in-scanner tasks **[3]**, with the exception of the tone task **[4]**.

      5.6.1.   LAB MEDIA: Table 2

      5.6.2.   LAB MEDIA: Table 2 *Video Editor: please emphasize Structured data columns*

      5.6.3.   LAB MEDIA: Table 2 *Video Editor: please emphasize Rando data columns*

      5.6.4.   LAB MEDIA: Table 2 *Video Editor: please circle Tone task data row*

Conclusion

6. Conclusion Interview Statements

6.1. **Julie M. Schneider**: We encourage researchers to include other individual difference measures to better understand how variability in statistical learning across domains and modalities relates to higher level processes **[1]**.

6.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

6.2. **Zhenghan Qi**: This protocol is a first step toward delineating how individual differences in statistical learning may account for variations in language outcomes in both typical and atypical development **[1]**.

6.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera