COMPARISON OF ACCURACY AND MOVEMENT FOR PHONOLOGICAL GRAIN SIZE MATCHING DURING FMRI SCANNING VERSUS OUTSIDE THE SCANNER

by

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This thesis entitled:

Comparison of accuracy and movement for phonological grain size matching during FMRI scanning versus outside the scanner

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Date: _____________

A final copy of this thesis has been examined by the signatories, and we find that the content and the form meet acceptable presentation standards of scholarly work in the above-mentioned discipline.

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ABSTRACT

Phonological and reading skill are highly intertwined with increased skill in one improving one in the other. Understanding how phonological information is represented in the auditory cortex (i.e., left superior temporal gyrus) will delineate underlying neurological differences between children with good versus poor reading abilities. The purpose of this study was to develop an imaging protocol that would result in high quality data, i.e., data with good accuracy and minimal movement in the scanner. A future study aims to examine the interactions between phonological and reading skill with the organization of small and large grain phonological processing in the superior temporal gyrus; therefore, the current study compares a group of children who completed a phonological grain size matching task outside the scanner to a single participant who completed the same task inside the scanner. All participants matched small and large grain targets within real and pseudo words (“sh” /“shoe” and “rill” / “thrill”). This study resulted in a clear protocol to improve the quality of data collected, both behavioral task data as well as fMRI imaging data. The results will be utilized as a study protocol going forward as additional children are scanned on this task.
ACKNOWLEDGEMENTS

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Introduction and Background

Reading involves mapping between letters and speech sounds and recognition of whole words or larger patterns of letter combinations (sight word reading). While there is extensive research investigating the network used for reading and the development of this network (Dehaene et al., 2010; Desroches et al., 2011; Dewitt and Rauschecker, 2012), less is known about the organization for speech processing based on phonological grain size (number of phones in words or parts of words). This study is part of a larger project lead by Christine Brennan, PhD CCC-SLP, investigating differences in the representation of speech sounds in the auditory cortex for children with and without dyslexia.

Previous studies with children revealed difference in the STG (superior temporal gyrus) based on phonological skill (Dehaene et al., 2010; Desroches et al., 2010) and reading skill (Christodoulou et al., 2014; Dehaene et al., 2010; Desroches et al., 2010; Shaywitz et al., 1998). Further, activation of the auditory cortex in typical adults revealed selectivity based on phonological grain size (or the number of speech sounds in words) (Brennan, 2014). Specifically, the mid-STG activated more for stimuli with two phones sounds whereas the anterior-STG/MTG (middle temporal gyrus) activated more for four phones. Additional analyses based on the data collected by Brennan (2014) revealed skill-based differences in the engagement of the mid-STG for small grain stimuli.

The current pilot study specifically focused on the differences of accuracy between real word phonological grain size matching and pseudoword phonological grain size matching between 10 participants who completed the matching task on a computer and a single subject who completed the task while in an fMRI scanner. Movement data was also analyzed to determine if the pilot subject was within the acceptable parameters of less than 2 mm in all
directions. Furthermore, a scanning protocol is introduced to prevent data collection errors, and to improve the quality of data. These findings will be critical as the larger study aims to extend this investigation to include the organization of the auditory cortex in children with dyslexia.

Children with phonological dyslexia exhibit difficulty in phonological skill and reading, creating a barrier to effective literacy acquisition (Shaywitz et al., 1998; Temple et al., 2001). Improving phonological skills results in improved reading skills (Goswami & Bryant, 1990; Wagner & Torgesen, 1987). In turn, improved reading appears to result in improved phonological skill (Ehri, 1989; Morais, 1991; Morais, Alegria, & Content, 1987). While these two skills are intrinsically intertwined, a clear understanding of the shared regions of the network that underlie these skills is critical for improving our understanding of individual differences in skills. Understanding what specific regions of the reading network are tied to phonological skill in typical children is necessary before determining what differs in children with dyslexia.

Recent work has begun to describe the organization of the auditory cortex based on phonological grain size. A previous meta-analysis investigating the organization of the auditory cortex based on phonological grain size found selective activation for small versus larger phonological grain size stimuli in the superior temporal cortex (DeWitt & Rauschecker, 2012). Brennan (2014) found direct evidence of selective activation based on phonological grain size in adults with typical reading skill. Determining if the auditory cortex is organized by phonological grain size in children is critical to understanding the development of the reading network. These results will be further critical for a comparison to children with reading disability in future studies.

One limitation of the previous study (Brennan, 2014) was that only pseudowords were used as stimuli. Pseudowords are word-like but have no meaning, such as “funa.” Even though
the pseudowords did not have meaning, hearing stimuli that is word-like could potentially engage representation of meaning as a person automatically searches for the meaning of something that sounds like a word. As a result, such stimuli may result in engagement of the MTG, a region highly associated with semantic processing (Binder et al., 1997; Brennan 2014). Therefore, the results reported by Brennan (2014) and by DeWitt & Rauschecker (2012) cannot definitively rule out activation of this region for semantic processing rather than to the large grain size. Therefore, the current study will include additional stimuli with real as well as the previously used pseudowords. If we find distinct regions for small and large grain size (i.e., anterior STG/MTG) for the real words (with two versus four phones) in future studies, then we will be more confident that the region selective to large grain stimuli is due to phonological grain size rather than meaning. To determine where small and large grain stimuli are processed in the brain of typically developing children, participants in future studies will be scanned using fMRI while being presented with spoken word and pseudowords with either two or four phones.

While previous studies of the neurophysiology of phonological processing and reading have found developmental and skill-based differences in the auditory cortex, specifically the superior temporal gyrus (STG) (Christodoulou et al., 2014; Dehaene et al., 2010; Desroches et al., 2010; Shaywitz et al., 1998), future studies will extend this to show organizational differences based on phonological grain size. Since reading skill requires management of grain sizes, skill-based differences in organization will identify the STG as an important neural correlate possibly underlying the development of reading skill. This result can then be extended to investigate children with dyslexia to determine if differences in speech sound organization underlie these deficits and motivate new treatment approaches. Literacy is a vital component of academic success and finding the root cause of disordered reading can aid intervention for
children who struggle to learn to read in the future. We expect to find similarities in accuracy of pseudoword and real word matching in small and large grain stimuli between the group and single subject. These findings will improve the quality of data in future studies, and inform us of subject qualities.

Specific Research Questions

1. Is there a difference between real word phonological grain size matching inside the scanner and outside the scanner? Is there a difference between small and large grain size matching?

2. Is there a difference between phonological grain size matching inside the scanner and outside the scanner? Is there a difference between small and large grain size matching?

3. Is movement data for the pilot subject within acceptable parameters (i.e., <2 mm in all directions)? Does analysis of movement differ for direction of movement, run order, or condition?

Methods

Participants

Eleven monolingual children (ages 8-12 yrs) were recruited from the Boulder area to participate in the study. These eleven children had a history of typical reading development and no current difficulties with phonological skill or decoding. A questionnaire ensured that participants met the following inclusionary/exclusionary criteria: native, monolingual English speakers with no neurological disease or psychiatric disorders, no history of ADHD/LD/Hearing impairment, and not taking medications that affect the central nervous system. These children completed a phonological grain size matching task for real words and
pseudowords on a laptop computer. An additional child, age 7 years, was recruited to participate in fMRI scanning. This child completed the same phonological grain size matching task while in the fMRI scanner as part of pilot testing to test the scanning parameters, the ease with which a child can complete the task in the scanner, and to identify best practices for future scanning of children.

All participants were recruited from the Boulder/Denver area and all are native English speakers. This study was approved by the Internal Review Board of the University of Colorado at Boulder.

**Design**

This study used a unique phonological grain size matching task that included large and small grain conditions for real words as well as pseudowords. Ten children completed the task outside the scanner and one completed the task during fMRI scanning. Accuracy data was analyzed and compared to determine the impact of completing the task in the scanner. Additionally, movement data from the child who completed the task during fMRI scanning was analyzed. These data as well as observations from the scanning session were considered in the development of the new scanning protocol.

**Experimental Task**

The experimental task included a phonological grain size matching paradigm. For the small grain stimuli (those with two phones), the child pushed the left button on the button box when they heard a target sound, such as “sh” when they hear the word “shoe”. For the large grain stimuli (those with four phones), he also pushed the left button when he heard a target set
of sounds, such as “rill” when they hear the word “thrill”. When the target sound or set of sounds was not heard, he pushed the right button on the button box.

Stimuli

Stimuli included pseudowords and read words with either two or four phonemes (speech sounds) that were used for the small and large phonological grain size conditions. Each stimulus consisted of synthetic speech and/or noise. Compared to natural speech, synthetic speech can be carefully controlled for length and loudness. The speech synthesizer in Praat (Boersma et al., 2012) was used to generate all stimuli. All pseudowords and words have the same fundamental frequency, rate, loudness, stress, and intonation patterns. Noise stimuli were created in Matlab using the Welch method that takes the generated pseudowords and/or words, maintains the original spectral and amplitude features, and converts each pseudoword into a unique noise signal. This method resulted in unique noise stimuli that match the frequency, spectra, and amplitude of the original pseudowords and words.

For the words and pseudowords, a noise signal either replaced one or more phones or was added to the stimuli to create the small and large conditions (see Table 1). Replacing phones with noise allowed for manipulation of grain size while other variables are held constant. When noise replaced phones, the length of the noise was adjusted so that all stimuli were equal in duration (approximately 800-850ms). For the real words, noise was added in the same positions as in the pseudowords to mimic and match length and structure. For the large grain stimuli, noise was added to the beginning or the end of the words/pseudowords so that there was some noise in every stimulus.

The pseudowords were created by combining eleven unique biphones. These biphones were selected because they included continuants paired with vowels (CV structure).
Continuants were selected because they are speech sounds produced with an incomplete closure of the oral vocal tract, are less variable over time, and can be easily controlled for length. None of the vowels in the pseudowords included diphthongs (i.e., gliding vowels in which two adjacent vowel sounds occur within the same syllable). The eleven biphones were selected because their acoustic waveforms show a clear distinction between the consonant-vowel transitions, resulting in cleaner separation of syllables and/or phones. The real words were selected from the CELEX database (Baayen, Piepenbrock, van Rijn, 1993). Selected words had either two or four phonemes. Additionally, ten typical adults completed a stimuli testing pilot study. Real word stimuli were presented via headphones and adults were asked to type the word they thought they heard. The real words were selected based on those with the highest average accuracy for the group of typical adults.

One control condition had all noise. Stimuli were presented in homogeneous blocks (several different stimuli from the same condition) with no item repetition. There were two grain size conditions (large, and small) and one control condition (noise only).

Behavioral responses to the active listening task performed during scanning included all button presses between 300 ms and 1300 ms after presentation. Minimum accuracy of >60% ensured the participant was awake and attending to the stimuli during scanning. Responses with accuracy <60% was not included in imaging analyses.

**Scanning Protocol**

Our participant lay in the scanner with his head position secured with foam padding. To minimize scanner noise, sound attenuating MRI safe ear buds and an MRI-safe padded hood was used in the bore (the center of the scanner where the participant is laying). A response box and alarm ball were used while in the scanner. Six functional runs (3.5 minutes each) included
pseudorandomized blocks from all conditions. Three runs included only pseudowords and three additional runs included only real words. Runs were pseudo-randomized using a mixed imaging design. Stimuli and block order were pseudo-randomized. No two sequential blocks were from the same condition. Blocks were separated by rest periods of 4 or 6 seconds (mean 5s). Run order was counterbalanced. Total functional scanning time was 28 minutes.

Images were acquired using a Siemens Magnetom Prisma fit 3.0 Magnetic Resonance Imaging System with a 32-channel head matrix coil for brain imaging. This was located at the University of Colorado, Boulder Intermountain Neuroimaging Consortium (INC). Gradient echo localizer images were acquired to determine the placement of functional slices. For functional images, a susceptibility weighted single-shot EPI (echo planar imaging) method with BOLD (blood oxygenation level-dependent) was used. The current study used parameters that have been optimized to minimize scanner noise during functional scanning: TR (ms)=2000, TE(ms)=29, flip angle=70°, matrix size=120x128, FoV=230x206.3mm, FoV phase=93.8, Bandwidth=1628 Hz/Px, slice thickness=1.8mm (no gap), number of slices=84, Base resolution=128, Phase resolution=100, Multi-band factor = 6. These parameters resulted in a voxel size of 1.8x1.8x1.8mm. A high resolution T1weighted 3D structural image was acquired for each participant and took approximately 9 minutes.

Data Analysis

Preprocessing included normalization and smoothing. Normalization is a technique that involves arranging the scanning image in reference to a template of a brain. This template of the “average brain” was extrapolated from a large sample of the population, and provides anatomical reference points. Scanning images can involve “spikes” in voxels, which can distort
the data. Smoothing is a technique that averages data points from surrounding voxels to account for misrepresentative data points; this technique made 3x3x3 mm voxels.

Behavioral data (i.e., accuracy) from all children were analyzed for real words and pseudowords with both small and large grain. While comparing a group to a single subject is typically not practiced, the statistics on these two groups were reported and discussed to further explore the accuracy differences between the group that completed the task on the computer, and the participant who completed the task while in the scanner.

Movement data from the child who was scanned was also analyzed and range of movement (in mm) was reported for each run as well as for the real word and pseudoword conditions.

Results

Accuracy on task

As previously mentioned, statistical analyses typically do not compare a group to a single subject due to differences in variance, number of data points, and general statistical rules. However, as this pilot study is investigating the accuracy differences between participants who completed the task outside and inside the scanner, as well as possible reasons for discrepancies, an ANOVA was used to compare the group of children who completed the task on a computer outside the scanner to the one child who completed the task in the fMRI scanner during scanning.

We found a significant effect of group for real word small grain phonological matching (F(1, 10) = 7.653, p = .024), with the computer group achieving significantly higher average accuracy than the child who completed the same task in the scanner (see Figure 1). There was a
significant effect of group for real word large grain phonological matching ($F(1, 10)= 14.509, p = .005$), with the computer group achieving significantly higher average accuracy than the child who completed the same task in the scanner. There was a significant effect of group for real word total accuracy of phonological matching ($F(1, 10)= 15.603, p = .004$), with the computer group achieving significantly higher average accuracy than the child who completed the same task in the scanner.

The same ANOVA statistical analysis was performed for pseudowords, and similar outcomes were found (see Figure 2). There was a significant effect of group for pseudoword small grain phonological matching ($F(1, 10)= 11.666, p = .009$), with the computer group achieving significantly higher average accuracy than the child who completed the same task in the scanner. There was not a significant effect of group for pseudoword large grain phonological matching ($F(1, 10)= 3.902, p = .084$). There was a significant effect of group for pseudoword total accuracy with phonological matching ($F(1, 10)= 8.417, p = .020$), with the computer group achieving significantly higher average accuracy than the child who completed the same task in the scanner.

**Movement in scanner**

The movement of the participant in the scanner prevented any analyses of imaging data that was collected. To be included for imaging data, movement must not exceed more than 2 mm in any direction, including acceleration along the x, y, and z axis, as well as rotating along the x, y, and z axes, called “pitch, yaw, and roll” (see Figure 3). An example of the subject’s scan with preprocessing (see Figure 4) shows a “blurriness” resulting from the excessive movement and indicating that the subject moved frequently throughout the task. Since the image was normalized and there were so many movements in all directions, the smoothed image became
blurred. An example of the raw imaging data before preprocessing reveals a “shadow” or movement artifact can be seen in the parietal and occipital region (see Figure 5). This movement pattern is consistent with movement along the x axis. While whole-brain analysis was attempted using SPM12 to determine the effect of condition on brain activation patterns, excessive movement resulted in imaging data that was of too low a quality to be reliable.

A statistical analysis was completed on the movement data as recorded by the scanner. The task was organized with three runs in each condition. Real words were presented during the first three runs and pseudowords were presented in the last three runs. The participant movement is reported by range (max-min in mm) in the planes (x, y, z) format (see Table 3, Figure 6). For all directions, runs, and conditions, there was a range of movement greater than 2mm, which exceeds the movement limitations needed to obtain high quality imaging data.

Repeated Measures ANOVA was completed with direction of movement (x, y, z), condition (real/pseudowords), and run order (1-6) as variables of interest. This statistical analysis was completed to determine if there was an effect for the individual variables and interactions between these 3 variables. (see Figure 7). A significant effect of condition was found (F(1,106) = 112.321, p <.001), with greater movement for the real words versus the pseudowords. A significant effect of run order was found (F(1,106) = 8.360, p=.005), with greater movement for runs 2 and 3 versus 1, 4, 5, and 6. No significant effect of direction of movement (x, y, and z) was found; however, there was a significant interaction between direction and run order (F(1,106) = 118.562, p <.001), with greater movement in the “x” plane for runs 2 and 5, greater movement in the “y” direction for run 6, and greater movement in the “z” direction for run 5. This indicates that the direction of movement was not consistent across runs, but in fact changed with each run. There was also a significant interaction between direction, run order, and
condition (F(1,106) = 25.581, p <.001), with greater extremes of movement occurring in each of the three directions for some runs in the pseudoword conditions, but with increasing movement with each subsequent run in those extremes.

Discussion

In the present study, we explored relationships between accuracy between real word phonological grain size matching and pseudoword phonological grain size matching while outside the scanner versus in the scanner during scanning. Accuracy was found to be lower for the child who completed the task inside the scanner. Additionally, movement during scanning fell outside acceptable parameters (i.e., >2 mm in all directions).

The participant who completed the task in the scanner was less accurate than the group who completed the task on the computer (see Table 2). This discrepancy in accuracy was observed for both grain size conditions and for real words and pseudowords. The lower accuracy may have been caused by multiple factors. One factor is a lack of practice before the scanning. Our participant briefly completed one short practice trial using a laptop immediately before scanning. As a result, his results may have been improved by increasing his comfort level with the task and increased practice performing the task. This could be rectified if future participants experience more extensive practice of the task prior to the day of scanning as well as immediately before scanning. This would ensure participants understand the task, and have adequate practice performing it, making it more likely to obtain higher accuracies during scanning.

It is also possible that female children would yield different results, since it has been documented that females develop language differently than males (Brown, 1973). Furthermore,
our subject was a male who is younger than our anticipated age group of 8 to 12 years of age, and could still be in the language development phase. The short term and working memory aspect of the task may also be too complex for a younger population to complete accurately. Consequently, it is possible that the data collected does not reflect a fully developed language system, and accuracy may be improved with participants who are a few years older.

Excessive movement was limiting factor in this study, as it led to imaging data that could not be analyzed for effect of condition on brain activation patterns. As with accuracy, excessive movement may have been due to a lack of practice in the scanner. Additional reasons for excessive movement could also be attributed to limited feedback about movement or participant qualities. The amount of movement observed in this participant provides compelling evidence that practice in the mock scanner is critical if movement of future participants will fall below the movement limitation of <2 mm. Since the participant’s movement decreased with subsequent runs, this child may have been able to stay still more after receiving feedback from the experimenters during scanning and as his familiarity with the task increased. To minimize movement caused by frustration with the task’s difficulty or by boredom, practicing the task while in the mock scanner would give confidence and familiarize the participant with the distracting scanner noise while completing the task. Additionally, providing extensive feedback as soon as the child is in the scanner should also help minimize movement in the beginning segment of scanning.

Furthermore, movement training can and should be implemented. The mock scanner at the INC facility includes a modified Wii remote headband, which tracks a child’s movement online (in mm) and provides the child with instant feedback via vibration if the participant moved outside of the parameters. These parameters can be modified by the experimenter online
as well, allowing the child to practice “staying still” with an increasing level of restriction. During fMRI scanning, the participant was observed to have movement beyond the 2mm criteria and excessive movement during 2 of the 6 trials. Interestingly, the observed movement was reflected in the high range of movement in Runs 2 and 3 (Table 3). When asked why he moved so much by his mother after leaving the INC facility, he “it felt good on his ears” and that the ear buds hurt his ears, indicating that movement may have been caused by discomfort. After receiving this information from the parent, we learned that the MRI tech had used the adult-sized ear buds. In future studies, experimenters should make sure that the MRI tech only uses child-sized earbuds unless a child is larger and needs the larger ear buds to block out noise more efficiently. This should make the task more comfortable and facilitate the participant staying still for longer.

Since the participant who was scanned was 7 years of age, he was younger than the target age for the future imaging study, which is aiming to recruit children ages 8-12 years. Therefore, this child may have less control of movement and less tolerance for staying still for the required amount of time as compared to the children the future study aims to include. This is consistent with previous studies that report greater difficulty scanning children younger than eight years of age due to excessive movement (Yerys et al., 2009). Consequently, a detailed scanning protocol is included in the Appendix to address these issues and prevent low accuracy in the future.

As previously mentioned, there was an interaction between movement and run order. Specifically, the participant’s movement decreased as the runs continued. This could indicate that he benefited from verbal feedback given during scanning but after each run about his observed movement. Since the condition (pseudoword versus real word) did not significantly interact with either variable, (run order or direction of movement), the condition did not seem to
affect movement. This can be interpreted as difficulty not playing a role in movement. This is unexpected since pseudowords are generally thought to be more difficult than real words. This information is useful for future data collection since experimenters can focus on condition and task practice as a way to improve accuracy and on comfort and movement practice as a way to reduce movement.

The future study that will involve scanning of child is being implemented on a different scanner compared to the previous adult study (Brennan, 2014). Additionally, the more standard imaging parameters used by other INC studies do not meet the needs of this future study. Specifically, the future study differs from other fMRI studies in that activation within specific regions of the superior temporal gyrus will be examined and compared. As a result, a smaller voxel size is needed in order to delineate regions which are anatomically very close together (as close as 10-15 mm). For the current project, scanning parameters needed to be developed that allowed for the collection of imaging data with a very small voxel-size. This required multiple trial and error runs without subjects as well as extensive input from the INC staff. Once parameters were found that could yield a small voxel size, one trial session with all runs was completed with an adult. Given that the current set of scanning parameters worked with an adult and a child, these parameters can continue to be used for future participants.

Future projects with more participants can focus on differences in organization for typical children with high and low phonological and reading skill, which will lead to a comparison between typically developing children and children with dyslexia. However, to accomplish this study, data will need to be accurate and include little movement during scanning to prevent data removal. Prevention measures such as practice sessions, movement education, and a list of prohibited or cautionary items while in the scanning room will be included in the scanning
protocol (included in the Appendix). This protocol will guide future studies to collect better data with higher accuracy and less movement, improving the quality of data collection.
Figure 1: Real word phonological grain size matching accuracy computer v. scanning

Accuracy on the phonological grain size matching task for real words done on a computer versus during scanning.
Figure 2: *Pseudoword phonological grain size matching accuracy computer v. scanning*

Accuracy on the phonological grain size matching task for pseudowords as completed on either on a computer outside the scanner versus in the fMRI scanner during scanning.
Directions of movement during fMRI scanning, including movement in three directions: x (also known as pitch), y (also known as yaw), and z (also known as roll).
Figure 4: fMRI image with smoothing

fMRI image with smoothing. Preprocessing of raw fMRI data included smoothing which resulted in an increase of noise in the images.
**Figure 5:** fMRI image without smoothing

fMRI image without smoothing. Before images were preprocessed, effects of movement are still apparent, including misaligned slices, and shadowing artifacts.
Figure 6. Range of movement

Range of movement mm (Max-Min) recorded in the fMRI scanner in each of three directions of movement (x, y, and z) for each run completed by the child who was scanned. The first three runs included only real word (RW) phonological grain size matching and runs four through six included only pseudoword phonological grain size matching. The runs are shown in order of completion during scanning. Analysis of movement did not show a significant effect of direction; however there was a significant effect of condition and of order.
Figure 7. *Average movement by condition, run and direction*

Average movement by condition, run, & direction (mm) by the one child who completed the task in the fMRI scanner during scanning. Analysis of movement shows a significant effect of run order and condition, but not direction.
Table 1. Grain size and noise conditions.

<table>
<thead>
<tr>
<th>LARGE - QUADRAPHONES</th>
<th>SMALL - BIPHONES</th>
<th>CONTROL - NOISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPPPX</td>
<td>PPX</td>
<td>XXXX</td>
</tr>
<tr>
<td>XPPPP</td>
<td>XPP</td>
<td></td>
</tr>
<tr>
<td>XPPPPX</td>
<td>XPPX</td>
<td></td>
</tr>
</tbody>
</table>

The large condition includes stimuli with four phonemes and the small condition includes stimuli with two phonemes. Placement of phonemes and noise were varied so that phonemes occurred in all positions. Placement of phonemes is indicated by a P and placement of noise is indicated by an X.
Table 2: Phonological grain size matching task accuracy for real words and pseudowords

<table>
<thead>
<tr>
<th></th>
<th>RW small</th>
<th>RW large</th>
<th>RW total</th>
<th>PW small</th>
<th>PW large</th>
<th>PW total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanner</td>
<td>0.40</td>
<td>0.51</td>
<td>0.46</td>
<td>0.23</td>
<td>0.38</td>
<td>0.29</td>
</tr>
<tr>
<td>Computer</td>
<td>0.628889</td>
<td>0.804444</td>
<td>0.716667</td>
<td>0.708889</td>
<td>0.672222</td>
<td>0.69111</td>
</tr>
</tbody>
</table>

Accuracy on the phonological grain size matching task for real words (RW) and pseudowords (PW) broken up by small and large conditions as well as for large and small combined completed on a computer outside of scanning (n=11) versus inside the fMRI scanner during scanning (n=1).
Table 3: Range of motion (mm) in fMRI scanner of three directions of movement (x, y, and z)

<table>
<thead>
<tr>
<th>Task order in Scanner</th>
<th>Condition</th>
<th>x</th>
<th>y</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RW</td>
<td>8.8725</td>
<td>10.5267</td>
<td>4.674</td>
</tr>
<tr>
<td>2</td>
<td>RW</td>
<td>17.6103</td>
<td>12.9594</td>
<td>3.0946</td>
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<td>3</td>
<td>RW</td>
<td>8.9927</td>
<td>13.7493</td>
<td>6.5998</td>
</tr>
<tr>
<td>4</td>
<td>PW</td>
<td>8.8019</td>
<td>7.321</td>
<td>5.3</td>
</tr>
<tr>
<td>5</td>
<td>PW</td>
<td>8.9238</td>
<td>5.3737</td>
<td>6.3138</td>
</tr>
<tr>
<td>6</td>
<td>PW</td>
<td>6.4975</td>
<td>9.9986</td>
<td>4.3314</td>
</tr>
</tbody>
</table>

Range of motion in mm (Max–Min) recorded in the fMRI scanner in each of three directions of movement (x, y, and z) for each condition and each run. The first three runs included only real word (RW) phonological grain size matching. Runs four through six included only pseudoword (PW) phonological grain size matching. The runs are shown in order of completion during scanning, with the first run indicated as having a task order of 1, the second run indicated as having a task order of 2, etc.
References


Appendix

Protocol for mock scanning and fMRI scanning

The following protocol was developed as a direct result of the data collected in this study and aims to reduce movement in the scanner and increase accuracy for the task when completed in the scanner during scanning. It is recommended that this protocol be followed for all future children participating in the study in order to ensure a higher quality of data.

Mock scanner session:

1. Introduce child to mock scanner room including photos, bore, scanning noise from stereo
2. Show pictures of fMRI images and explain differences of blurry images with movements and clear images without movement, reiterate why we are practicing in a mock scanner (to minimize movement and increase comfort)
3. Show Wii remote headband to demonstrate how it measures movement
4. Explain/demonstrate how moving other body parts (legs, arms) can contribute to head movement
5. Weigh child on scale
6. Set up child to perform task on the laptop
7. Place bedsheets on fMRI sliding table for cleanliness
8. Ask child to climb on fMRI sliding bed (stabilize bed, as it is on wheels)
9. Show them the mouse (simulates button response box, placed in dominant hand), practice multiple trials to ensure child is comfortable with the task and clear about which button to push.

10. Place wireless Bluetooth headphones on child, lay down, place head coil over head

11. Place corresponding Bluetooth toggle in USB port

12. Roll child into mock bore

13. Start scanner noise on stereo

14. Begin short films/audiobooks to simulate time when anatomical scan is occurring

15. Begin task

16. Provide feedback for child for appropriate/excessive movement while in mock scanner using the Wii headband movement monitor

   a. Have the child practice moving versus staying still. Have them practice as the movement criteria on the Wii headband movement monitor is reduced from 18mm to 1mm.

   b. If necessary, have the child practice staying still without the task (he/she can watch a movie), before returning to the task.

   c. The child should be able to stay still (<2mm movement) without any more than 2-3 movements in excess of 2mm during a 4 minute period (the average length of a run). If a child moves too much or too frequently, have the come back for another practice mock scanner session before scheduling them for fMRI scanning.

17. Roll child out of mock scanner
fMRI Scanner Session:

1. Greet child and guardian at entrance of facility
2. Bring to designated testing room, ask child and guardian to fill out appropriate paperwork, explain purpose of paperwork
3. Review fMRI safety requirements- no metal hairbands, braces, empty pockets
4. Review practice task immediately before task to refresh child on task and expectations
5. Allow child to change into provided pajamas if wearing metallic elements (zippers, sequins), change hairstyle if in a ponytail, anything that might cause discomfort when laying supine for approximately 40 minutes.
6. Ask child to use the restroom, remind them that they will not be able to leave the scanning room once the task begins
7. Weigh child on scale, report to fMRI technician
8. Lead child and guardian to fMRI control room, show child bore through the glass
9. Inform/remind child and guardian that we can talk with them even though they are in a different room, but that we need to talk first in order for us to hear them
10. Introduce child to fMRI technician
11. Child will be lead into fMRI room, set up by technician

Remind the MRI tech of all of the following:

a. Make sure MRI tech uses the child-sized earbud
b. Make sure MRI tech puts additional padding around the child’s head before placing the head coil to prevent movement).
12. Make sure to verbally confirm with the child that the ear buds are comfortable and that they are comfortable before scanning is started. Make adjustments as necessary.

13. Begin stimuli runs, verbally checking in with the child after and before each run and reminding the child to stay “as still as a statue.”
   
a. Make feedback about movement specific (i.e., “you are nodding your head up and down” or “you are shaking your head to the side”) and ask why the child is moving if movement is noted. Remind them not to move at all during scanning. Please remember that it is important to be proactive when addressing movement – so be observant and check in about movement frequently.
   
b. You can keep the child aware of how many runs they have left (counting down from 6) as scanning proceeds. This may help mitigate movement if they know they are closer to being done.
   
c. Tell the child before each run if they are doing the real word or pseudoword task (call it fake words for the child). This will hopefully improve accuracy on the task.

14. When the child is done, notify him/her that scanning is completed. The fMRI Tech will escort the child out of scanning room.