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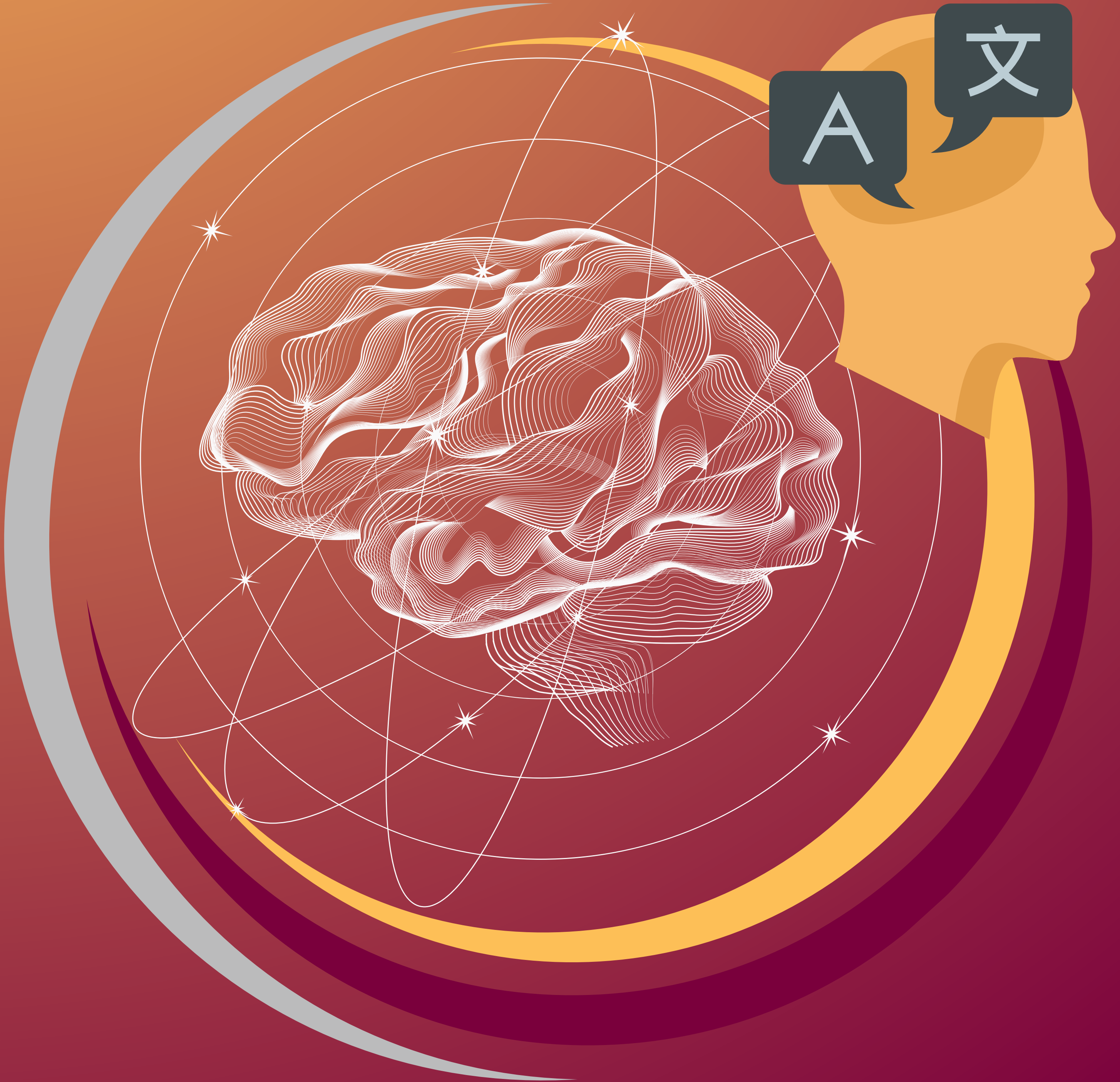

Editor’s Note

In this Summer-Fall 2024 issue of *The ARiEAL Research Magazine*, we provide an avenue for student trainees to disseminate high-quality and original research alongside spotlighting current issues within the field of linguistics and languages. As a research center, ARiEAL brings together a community of researchers ranging from undergraduate and graduate trainees. We aim to enable our trainees to excel in problem-driven scientific research in fundamental, experimental and applied linguistics.

This magazine serves to amplify the academic impact and outreach of our trainees’ research. The breadth of our community and research reflects the interdisciplinarity of our centre — we have created a supportive environment for researchers to cross traditional boundaries and produce socially impactful projects. Our projects extend to the worlds of Health Sciences, Life Sciences, Engineering, Social Sciences, and Humanities. The pieces that were selected for this issue bear witness to our commitment to diverse and beneficial research.

In this issue, a recent graduate from the Cognitive Science of Language master’s program, Fiza Ahmad, addresses the challenges associated with the inclusivity of current research methods in language sciences. Simran Sandal, a master’s student in Cognitive Science of Language, leads us through an exploration of the perceptual differences among traumatic brain injury patients and proposes an experimental design for speech perception and production in Autistic Spectrum Disorders. A recent graduate from the Psychology, Neuroscience, and Behaviour program, Shruthi Viswanathan, examines the roles of prosody during language acquisition. Finally, Robin Komarniski, an undergraduate student in the cognitive science of language program, proposes an experiment evaluating code-switching.

The ARiEAL Research Magazine, Volume 2 is composed of high-quality and innovative research that reflects the interdisciplinarity and talent at ARiEAL. We are proud to celebrate our trainees’ accomplishments and research that not only pushes academic knowledge but has societal benefits.

Your 2024 Editorial Team,

Fiza Ahmad
Brianna Griska-Macphee
Simran Sandal

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The Role of Rhythm in Phonological Memory for Language

SHRUTHI VISWANATHAN, B.Sc

The Role of Prosody in Language Acquisition

When individuals repeat sentences in the absence of meaning, they may rely on prosodic cues to remember the phonological forms of the unfamiliar words in the sentences. Prosody refers to temporal patterns such as the stress, intonation and general rhythm of speech. These aspects function as suprasegmental linguistic features across phonemes, syllables and phrases (Myers et al., 2019). Phonemes refer to the distinct units of sound in a language, which distinguish the words from one another. Stress, intonation and rhythm of the sentence can help with representing collections of phonemes in chunks of language, such as syllables, words and phrases.

Prosody has been shown to play a crucial role in language learning. Newborns are able to discriminate rhythm at a segmental level, which means that they can differentiate between the discrete units of speech such as the consonants and vowels (Provasi et al., 2014). This provides evidence that as humans we are able to perceive, represent and discriminate rhythm from a young age. This sensitivity to rhythm in language plays a role in language acquisition. It can help language learners understand the meaning of a sentence. For example, certain prosodic features found in motherese, or infant-directed speech, involve amplifications in duration and frequency. This results in stressed syllables being louder, longer, and higher in pitch, making the speech more captivating for infants than other types of sounds (Myers et al., 2019).

Prosody can also carry important semantic and pragmatic information. For example, in English, a rising intonation at the end of a sentence may indicate a question, while a falling intonation conveys a statement. Prosody can also convey emotions effectively in speech. It is important that language learners are not monotone and b rapport with native speakers. In a study, participants of Chinese and British background were asked to recognise pseudo sentences which were produced in an angry, disgusted, fearful, happy, neutral, sad or surprised tone of voice. The results indicated that members of each cultural group displayed higher accuracy in recognizing the utterances made by a member of their own cultural group (Paulmann and Uskul, 2014). The perception of rhythm in language may also be adaptive to the linguistic background or even cultural practices of the listener. Therefore, prosody can be tied closely to cultural norms and conventions, and can provide insights into cultural understanding between native speakers.

In one study (Cohen, Douaire and Elsabbagh, 2001), the effect of linguistic prosody on memory was examined in 20 subjects. The participants listened to passages varying in intonation (normal, monotonous, or altered). They read the same passages with varying punctuation (appropriate, no punctuation or altered). The results showed that altered prosody and punctuation impaired word recognition and text comprehension. In Experiment 1, altered prosody, which disrupts the alignment between prosodic cues and syntactic structure, impairs word recognition and comprehension by confusing listeners about sentence boundaries and relationships. This makes it harder to decode and remember information. Normal prosody facilitates understanding by providing clear rhythmic and intonational cues that align with grammatical structures, while monotonous prosody reduces but does not completely eliminate these cues. Similarly, Experiment 2 found that altered punctuation, by conflicting with syntactic structure, similarly hinders text comprehension and word recognition, highlighting the importance of consistent prosodic and punctuation cues for effective language processing. The ability to detect changes in intonation hints at how linguistic prosody offers clues for assessing sentence structure. Moreover, linguistic prosody aids in the semantic encoding of lexical units (Cohen, Douaire and Elsabbagh, 2001). This provides evidence to the hypothesis that lack of semantic context leads adults to rely on temporal and rhythmic cues to learn words.

Processing Temporal Patterns in the Brain

In a study by Service et al. (2022), participants tapped temporal sequences of short and long beeps and repeated meaningless sentences. These tasks showed that short term memory for auditory temporal patterns and meaningless sentences predicted the learning of foreign word forms. However, the relationship between memory for temporal patterns of beep durations seemed to have its effect through short-term-memory for sentence-like material. Short term memory stores information for a few seconds and is a part of our working memory. In the framework developed by Baddeley and Hitch (1974), working memory is thought to have a sub- system known as the phonological loop which processes speech-based information. Memory for the order and arrangement of phonemes within syllables, as well as words within patterns, plays a significant role in language acquisition.

One dimension of the formation of verbatim memories may be their temporal structure. Our brain anticipates the timing of events by making predictions of when the event will occur. Higher-level brain functions, such as language processing, significantly influence our expectations regarding the timing of events, a phenomenon referred to as top-down processing. This mechanism is engaged in the processing of temporal patterns during the tone task (Rimmele et al., 2018).

Research conducted by Service et al. (2022) revealed that the capacity to recall temporal patterns of sounds is associated with word acquisition using Turkish words for English speaking participants. However, this correlation was affected by an individual's proficiency in reproducing meaningless (Jabberwocky) sentences sounding like English. The skill of reproducing temporal patterns thereby appeared to aid in retaining the sequence of pseudowords and syllables, thereby facilitating language learning.

Processing and representing temporal patterns is one of the main abilities of the human brain. However, exactly how the brain represents serial order in language is not known. Some studies suggest that serial order representation in our short-term memory is not dependent on the timing of the events, but rather on event-based codes (Gorin, 2020). Other authors (Paton & Buonomano, 2018) have proposed that depending on the computational demands of a given task, the brain may employ various mechanisms to gauge time and process temporal sequences.

Notably, the dorsal striatum and the supplementary motor area emerge as pivotal brain regions contributing to the organization of beat-based temporal anticipation. Furthermore, the motor system plays a significant role in forecasting the timing of events, underscoring its involvement in temporal cognition (Cannon & Patel, 2021). At a higher cognitive level, functions such as motor control and language processing exert a lot of influence over our anticipations regarding temporal occurrences, thus shaping our perception of temporal patterns and events.

Phonological Loop and Short-Term Memory for Verbal Material

Baddeley and Hitch, 1974 proposed the existence of the phonological loop- a component of working memory which is specialized for the retention of verbal information over a short period of time. The function of the phonological loop is also to help learn new words, which is crucial for language development. The loop has two components, namely the 1) Phonological Store, and 2) Articulatory Rehearsal Component. The phonological store holds information in phonological form, which refers to the way in which information is encoded in terms of its auditory or sound-based characteristics. For instance, when you hear a word or a sequence of sounds, the phonological form is how those sounds are stored and maintained in your memory in terms of the phonemes or syllables. As an example, the sounds /p/ and /b/ in "pat" and "bat" are phonemes that are encoded. The articulatory rehearsal component is a subvocal rehearsal process which maintains decaying representations in the phonological store (Baddeley and Hitch, 1974). The phonological store is critical for learning new words. This comes from studies where children repeat nonwords or unfamiliar words. The researchers observed that repetition starts within 1 second of hearing the nonword, which typically lasts less than 1 second.

Considering that the phonological store's capacity is estimated at about 2 seconds, and children can repeat immediately, the role of rehearsal in nonword repetition seems minimal. Performance depended on how well the child can briefly store the sounds they just heard (Gathercole, Willis, Baddeley, & Emslie, 1994). Therefore, the study concluded that nonword repetition primarily measures the capacity of the phonological store, not rehearsal ability. When we hear words or verbal stimuli, they are briefly held in the phonological store which allows us to retain verbal material in our minds. This explains the importance of the phonological loop in providing short-term memory for verbal material.

When individuals encounter unfamiliar prosody in speech, the phonological loop helps encode auditory information into phonological representations. This may occur by parsing the speech into units, syllables, stress patterns and rhythms. This process is responsible for maintaining verbal material in the phonological store. The verbal material held in the phonological loop can be manipulated and retrieved as well. Verbal short term memory has also been shown to be related to vocabulary and grammar learning in children (Verhagen & Leseman, 2016).

The Current Study

The current study investigates short-term memory (STM) for meaningless language sequences with natural prosody or manipulated prosody. It also investigates STM for sentences with familiar and unfamiliar phonology. It differs from previous research in several key aspects. Firstly, past studies have examined the relationship between memory for non-linguistic rhythm and familiar or unfamiliar prosody on foreign language learning. This study examines how short-term memory (STM) is influenced by linguistic sequences featuring both unfamiliar sounds (phonology) and unfamiliar rhythmic or intonational patterns (prosody). In contrast, previous research has primarily explored how STM is affected by altering the order of familiar-sounding elements or by changing the prosody within sentences that use familiar sounds. Essentially, while past studies focused on scrambled familiar patterns, this study looks at the impact of both new sounds and new rhythmic structures on memory. Additionally, the current study diverges from prior research by using Tamil as the language for the foreign language repetition task. This departure from previous studies, which have focused on other languages, such as Turkish and Urdu, allows the investigation of the generalizability of the previous findings to Tamil, which presents its own distinct prosodic characteristics.

Tamil is a Dravidian language spoken in the Indian state of Tamil Nadu, and in Sri Lanka. Certain syllables may be pronounced with a higher pitch which contributes to the prosodic structure of the language. The stress is placed on the first syllable of a word. The length of the syllables and pitch variations contribute to the prosodic prominence of words in Tamil. In stress-timed languages, such as English, the interval of time between stressed syllables has been suggested to stay equal (Ramus, 2002). These differences in timing help us differentiate between different prosodic patterns. In Tamil stressed and unstressed syllables occur at equal timing intervals, unlike in stress-timed languages, where stressed syllables occur at regular intervals. The syllables also have equal timing regardless of the number of phonemes. Due to this rhythmic pattern Tamil has a characteristic flow and musicality. Tamil sentences may also seem shorter due to the language's agglutinative nature, where extensive grammatical information is conveyed through the attachment of affixes—prefixes, suffixes, infixes, and sometimes circumfixes—to root words. Affixes modify the meaning or function of words by adding nuances such as tense, number, case, or part of speech, allowing Tamil to pack more information into fewer words. Additionally, Tamil often omits subject pronouns when they are implied by verb conjugation, uses compound words to combine multiple concepts into one, and relies on contextual clues to convey meaning concisely. These morphological features collectively contribute to the succinctness of Tamil sentences.

We use three tasks in our study 1) Tone Repetition Task, 2) Jabberwocky Sentence Repetition with original, and scrambled syntactic word order. The original word order refers to presenting sentences or phrases in their natural, grammatically correct order. The scrambled word order refers to rearranging the words in a sentence to disrupt the normal syntactic structure, 3) Foreign Sentence Repetition. Participants were required to replicate by tapping a temporal pattern of 10 tone tokens, consisting of short and long beeps. This task was scored for proportion of correct short and long taps that matched the duration of the respective tone tokens. They were further asked to repeat 20 meaningless Jabberwocky sentences with familiar or manipulated prosody. In the final task they were expected to repeat 15 sentences in the Tamil language.

Based on previous findings, we hypothesize that performance on the new prosody Jabberwocky (non-word) sentence task would correlate with the tapping task, since both tasks are assumed to depend on the ability to represent rhythmic material, that is processing temporal patterns. We also predict that the ability to repeat sentences in a foreign language would correlate with the accuracy of performance on the temporal pattern task.

Methods

Participants

For this study, 30 Canadian University students (mean age= 18.5, female= 21, male= 9) with no reported visual or auditory problems were recruited. Data from 30 participants was used for analysis.

Participants were recruited using McMaster University research participant recruiting platforms (McMaster PNB SONA, and Linguistics SONA). All participants were native English speakers with no experience in Tamil or related languages. A letter of information was signed by each participant prior to the experiment. All participants also provided online consent to participate in this experiment in line with the ethical standards of the Declaration of Helsinki.

This study was cleared by the McMaster Research Ethics Board (MREB) in Hamilton, Ontario, Canada. After being tested, participants were sent a debriefing sheet and received a course credit as compensation for their time.

Stimuli

Participants completed tasks in this experiment that comprised of three different types of stimuli: tones (Tone Task), sentences (two Sentence tasks- English-based Jabberwocky, and Tamil).

For the tone task, ten tone sequences consisting of seven alternating long and short tokens of a tone were used. These sequences were obtained from a similar tone task used by Horzum (2020). They were generated using Audacity, and the short tones were set to be 200 ms in length, and the long tones 800 ms in length. On average, the sequences were 5157.5 ms long.

In the English Jabberwocky sentence repetition task, 20 meaningless sentences consisting of pronounceable nonwords were recorded by the same female native English speaker. Out of these sentences, 10 consisted of normal prosody, while 10 consisted of altered prosody. Normal prosody involves intonation, stress, and rhythm that align with the syntactic and semantic structure of a sentence, helping listeners easily parse and understand the meaning by signaling boundaries and emphasis, such as using pauses and pitch changes at natural sentence breaks. In contrast, altered prosody disrupts these typical patterns by creating mismatches between prosodic cues and the sentence's grammatical structure, such as placing unexpected pauses or altering pitch in ways that confuse the listener. The word order of the Jabberwocky sentences was changed using audacity software, by replacing the verbs with nouns. Ultimately this changed the syntax of sentence, and hence the prosody, which made up the altered prosody sentences.

The sentences ranged between five to six words, six to eight syllables. On average, the sentences were 2373.6 ms in length.

In the Foreign Sentence Repetition task, 15 (5 for practice, and 10 for the actual trial) auditory Tamil sentences were used. All the Tamil stimuli were recorded by the same female native Tamil speaker, using Audacity software, and edited using Praat software. The study used Tamil sentences specifically constructed for this task. The sentences comprised of 3 to 4 words, with 6 to 7 syllables. The sentences were designed to be simple and consist of short words. On average, the sentences were 2000 ms in length.

The foreign language (Tamil) sentences were recorded in a soundproof room using Praat software (version 6.1.03). The stimuli were high pass filtered at 150 Hz to remove any ambient or unwanted sounds at a 6 dB per octave, and a 5 ms rise/fall time was applied to the beginnings and ends of sentences. All files were loudness-normalized to 70 db. The recordings were saved as WAV files.

Tasks

We have three tasks in this experiment:

1. Tone repetition task
2. Jabberwocky sentence repetition task
3. Foreign sentence task

The current study used Tamil as its language of interest. Tamil is a language with its own unique prosodic patterns. Stress can be applied to trisyllabic words in both a syllable timed and stress timed manner. In syllable-timed words, each syllable takes roughly the same amount of time to produce. In stress-timed words, emphasis is placed on certain syllables within words. As an example, the trisyllabic Tamil word "padika" is pronounced as pa-di-ka, with equal amounts of time required to pronounce each syllable. If we consider the word "sapadral", the stress is placed on the "ral" syllable with it being pronounced as "raal".

Participants completed three tasks that varied in phonological (speech sound) and prosodic (speech rhythm and melody) novelty: 1) Tone rhythm repetition-by-tapping task, 2) Jabberwocky(nonsense) sentence oral repetition task, and 3) Foreign Sentence (Tamil) oral repetition task.

Study Procedure

The experiment was coded in PsychoPy (version 2023.2.3). The experiment was run on an Apple iMac desktop computer. Participants wore good-quality headphones (SONY) during the duration of the experiment. The entire experiment took between 30 minutes to an hour to complete. The audio recordings were reviewed to score participants on the Jabberwocky and Tamil task.

Task Procedure

Each task began with practice trials before the actual trials began. Breaks were included between tasks if required.

Tone Task. In this first task, participants were asked to carefully listen to tone sequences, consisting of seven long or short tokens. Participants then immediately replicated the rhythmic sequences by tapping a key on their keyboard. Participants had a response window of 8000 ms after each sequence to recreate its temporal structure. Ten sequences were presented. The tone sequences were adopted from Horzum (2020)'s Tone Task. Based on earlier experiments, if the participant pressed the key for under 400 ms, it was considered a short key press, and if they pressed the key for longer than 400 ms, it was considered a long press. This 400 ms threshold was decided after analysing participant responses from Horzum 2020's data, where short tones were held for an average of 250 ms, and long tones were held for an average of 550 ms.

English Jabberwocky (Nonword) Sentence Repetition Task. Jabberwocky refers to a string of nonsense or meaningless sounds or words with no semantic content, but morphological sentence structure. In this task, participants were presented with 5 practice trials. Participants were asked to listen to each sentence and verbally repeat it. If they were unable to recall a syllable, they were prompted to say "blank". Participants were scored on syllable and word scales. They were given one point for each correctly pronounced syllable, one point for each correctly recalled word, and no points for incorrect syllables or words, respectively.

Tamil Sentence Repetition Task. Participants listened to 5 practice sentences and were asked to verbally repeat them. The actual trials consisted of 10 sentences, and participants were required to recall these. If they were unable to recall a syllable, they were prompted to say blank. Participants were given 1 point for each correctly pronounced syllable, 0.5 points for partially correctly pronounced syllables for the syllable score and one point for each correctly recalled word, 0.5 points for partially correctly pronounced words and no points for incorrect responses on the word scale.

Results

Scoring

The Tamil Sentence Task was scored by a native Tamil speaker and the Jabberwocky sentence tasks were scored by a native English speaker and the same native Tamil speaker. Even numbered participants were scored by the native English speaker, while odd numbered participants were scored by the same native Tamil speaker.

Descriptive Statistics

Descriptive statistics for the independent and dependent variables are shown in Table 1. The correlation between the original correctly repeated proportion of Jabberwocky syllables and Tapping Accuracy (*r*(30) = .305) was not significant. However, a trend was observed in the positive direction which is observed in Figure 1.

There was no significant correlation between the Tapping accuracy and the proportion of correct words in the Jabberwocky sentences with original prosody. (*r*(30) = 0.197). Figure 2 shows the plot between the two tasks. A trend was observed in the positive direction.

A significant correlation was observed between the performance on the tapping task and the proportion of correct syllables on the new prosody jabberwocky sentences (*r*(30) = 0.365, *p* = 0.048). This indicates that performance on the two tasks may depend on rhythmic ability.

There was no significant correlation between the Tapping accuracy and the proportion of attempted words in the Jabberwocky sentences with new prosody. (*r*(30) = 0.210). Figure 4 shows the plot between the two tasks. A trend was observed in the positive direction. This correlation was slightly higher than the correlation between the tapping accuracy and proportion of correctly recalled words in the original prosody sentences.

There was no significant correlation between the Tapping accuracy and the proportion of correctly repeated syllables in the Tamil Sentences (*r*(30) = 0.008). Figure 5 shows the plot between the two tasks. This correlation was near zero and lower than the correlation between the tapping accuracy and the jabberwocky sentences.

There was no significant correlation between the Tapping accuracy and the proportion of correct words in the Tamil sentence task (*r*(30) = -0.006). Figure 6 shows the plot between the tapping accuracy and proportion of correctly recalled words in the Tamil sentence task. The correlation was near zero.

Discussion

In this study, we hypothesized that performance on the new prosody Jabberwocky sentence task would correlate with the tapping task, since both tasks are assumed to depend on the ability to represent rhythmic material. Based on previous findings, we predicted the ability to repeat sentences in a Foreign Language (Tamil) would correlate with the accuracy of performance on the temporal pattern task. The specific focus here was to find out what kind of information affects STM in the phonological loop.

We found a significant correlation between the tapping accuracy and the proportion of correct syllables in the new prosody jabberwocky sentences. This supports our hypothesis that the new prosody Jabberwocky sentence task and the tapping task both depend on the ability to represent rhythmic material. Participants performed better on the new prosody sentences. Therefore, we can conclude that short term memory for verbal material, as represented in the phonological loop is affected by altered sentence prosody. Since participants were able to recall sentences with altered prosody more effectively, it suggests that the phonological loop might be more adept at handling and storing short-term memories of such material. This improved recall could be due to how prosody influences the processing of auditory information. Specifically, prosody—the rhythmic and melodic aspects of speech—plays a crucial role in helping the phonological loop by aiding in the parsing of sentences and understanding their structure and meaning. When prosody is altered, it might create distinct and memorable auditory patterns that make the sentences stand out more in memory. This enhanced distinctiveness could help the phonological loop maintain and retrieve verbal information more accurately by providing clearer cues for segmenting and organizing the material. In essence, prosody helps the phonological loop by highlighting important aspects of the sentences, thus improving both encoding and recall of the verbal information. The altered sentence prosody is produced by scrambling the order of word-like. Altering the prosody of sentences may enhance sentence repetition due to enhanced STM for the verbal elements in the sentence. The correlation between the tapping accuracy and proportion of attempted words in the new prosody sentences was not significant, however there was a trend in the positive direction.

A future study can aim to replicate the study using a larger sample size which could produce statistically significant results. We did not find a significant correlation between performance on the Foreign Language Task and the rhythm task. We hypothesize that the Tamil sentences may have been too easy for the participants. Future studies can also aim to replicate it using Tamil sentences which place higher load on short-term memory, comprising more than 4-5 words, and more than 7-8 syllables.

We also did not find any significant correlations between the original prosody Jabberwocky syllables and words and the rhythm task. Although the study was carefully designed and conducted, the possibility of having native English speakers, who were not linguists to score the Jabberwocky tasks may have made the scoring of the tasks too conservative. Therefore, to ensure reliability of the results it is necessary to implement inter-rater scoring and recheck the scoring of the tasks. We also predict that the Jabberwocky task may have been too difficult in comparison to the Tamil sentence task for the participants which may have produced a lowered performance on the original prosody sentences.

The Jabberwocky sentences may have been more challenging to recall compared to the Tamil sentences because they contained longer words and were generally longer sentences. This increased length could have made it harder for participants to remember the sentences. Moreover, since Jabberwocky sentences used non-words with no inherent meaning, participants might have struggled to decipher and remember them, further complicating recall.

Furthermore, our sample size was limited to only 30 undergraduate first year students which could be a factor that affected our results. Future studies can aim to replicate the study using a larger pool of participants.

The study provides a diverse data set of Tamil sentences which can be utilized in future studies to test the effects on Foreign Language Learning. This dataset can serve as a valuable resource for researchers interested in investigating various aspects of language processing and prosody perception.

Conclusion

From this study, we were able to conclude that rhythmic ability helped with performance on the new prosody Jabberwocky sentence repetition. We were not able to conclude if rhythmic ability helped with foreign language repetition (Tamil). However, the ability to repeat words and syllables in a new prosody proved to be a good predictor of word repetition in a foreign language (Tamil). Most participants who performed well on the new prosody repetition also performed well in the Tamil sentence repetition. The study was conducted on Native English speakers, however some participants had familiarity with French and Arabic, therefore there may have been an effect of bilingualism on the study. Therefore, for future studies it would be beneficial to exclude participants who know other languages and conduct the study on purely Native English Speakers. Furthermore, the sample size can be increased to provide a better representation of the targeted participants.

TABLES & FIGURES

Table 1

Descriptive data for the proportion of correctly recalled beats in the Tone Task, syllables and words in the Jabberwocky Tasks for original and new prosody, and in the Tamil Sentence Task.

	Tapping accuracy	**Orig Jabberwockysyls**	**New prosody Jabberwockysyls**	**Orig Jabberwockywords**	**New prosody Jabberwockywords**	**Tamil syls**	**Tamil words**
N	30	30	30	30	30	30	30
Missing	0	0	0	0	0	0	0
Mean	0.698	0.514	0.486	0.504	0.498	0.683	0.626
Median	0.700	0.527	0.451	0.500	0.491	0.716	0.663
Standard deviation	0.0765	0.135	0.134	0.152	0.156	0.127	0.150
Min	0.528	0.284	0.236	0.204	0.236	0.431	0.318
Max		0.838	0.778	0.889	0.855	0.846	0.826

Table 2

Correlation between the Rhythm Task (Tapping Accuracy) and proportion of correct syllables for the Jabberwocky Sentence Task with Original Prosody sentences (Orig Jabberwocky syls)

		Tapping accuracy	Orig Jabberwocky syls
Tapping accuracy	Pearson's r	—	
	df	—	
	p-value	—	
Orig Jabberwocky syls	Pearson's r	0.305	—

df	28	—
p-value	0.101	—

Table 3

Correlation between the Rhythm Task (Tapping Accuracy) and proportion of correct words in the Jabberwocky Sentence Task with Original Prosody (Orig Jabberwocky Words).

		Tapping accuracy	**Orig Jabberwocky words**
Tapping accuracy	Pearson's r	—	
	df	—	
	p-value	—	
Orig Jabberwocky words	Pearson's r	0.197	—
	df	28	—
	p-value	0.297	—

Table 4

Correlation between the Rhythm Task (Tapping Accuracy) and proportion of correct syllables with Jabberwocky Sentence Task with Switched Prosody (New Jabberwocky Syls)

		Tapping accuracy	**New prosody Jabberwocky syls**
Tapping accuracy	Pearson's r	—	
	df	—	
	p-value	—	
New prosody Jabberwocky syls	Pearson's r	0.365 *	—
	df	28	—
	p-value	0.048	—

Note. * p < .05, ** p < .01, *** p < .001

Table 5

Correlation between the Rhythm Task (Tapping Accuracy) and proportion of attempted words with Jabberwocky Sentence Task with Switched Prosody (New Jabberwocky Words)

		Tapping accuracy	**New prosody Jabberwocky words**
Tapping accuracy	Pearson's r	—	
	df	—	
	p-value	—	
New prosody Jabberwocky words	Pearson's r	0.210	—
	df	28	—
	p-value	0.265	—

Note. * p < .05, ** p < .01, *** p < .001

Table 6

Correlation between the Rhythm Task and proportion of correctly repeated syllables in the Tamil Sentence Task.

		Tapping accuracy	**Tamil syls**
Tapping accuracy	Pearson's r	—	
	df	—	
	p-value	—	
Tamil syls	Pearson's r	0.008	—
	df	28	—
	p-value	0.967	—

Note. * p < .05, ** p < .01, *** p < .001

Table 7

Correlation between the Rhythm Task and proportion of correct words with Tamil Sentence Task

		Tapping accuracy	Tamil words
Tapping accuracy	Pearson's r	—	
	df	—	
	p-value	—	
Tamil words	Pearson's r	-0.006	—
	df	28	—
	p-value	0.973	—

Note. * p < .05, ** p < .01, *** p < .001

Figure 1

Correlation plot between the Rhythm Task (Tapping Accuracy) and proportion of correct syllables for the Jabberwocky Sentence Task with Original Prosody sentences (Orig Jabberwocky syls).

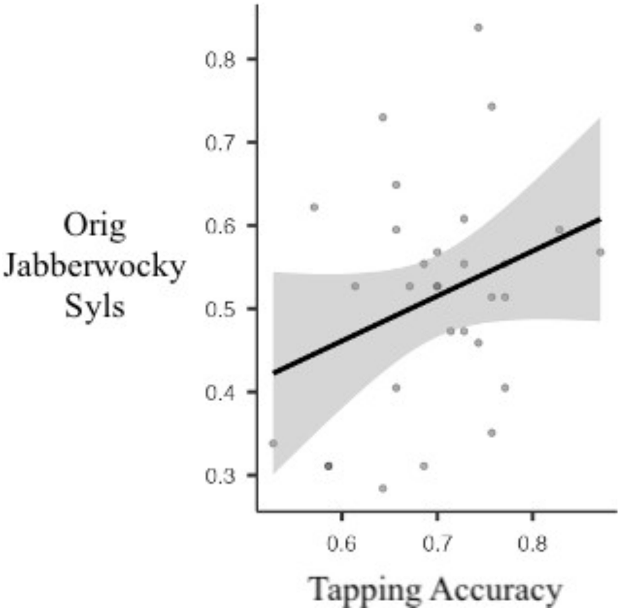


Figure 2

Correlation plot between the Rhythm Task (Tapping Accuracy) and proportion of correct words in the Jabberwocky Sentence Task with Original Prosody (Orig Jabberwocky Words)

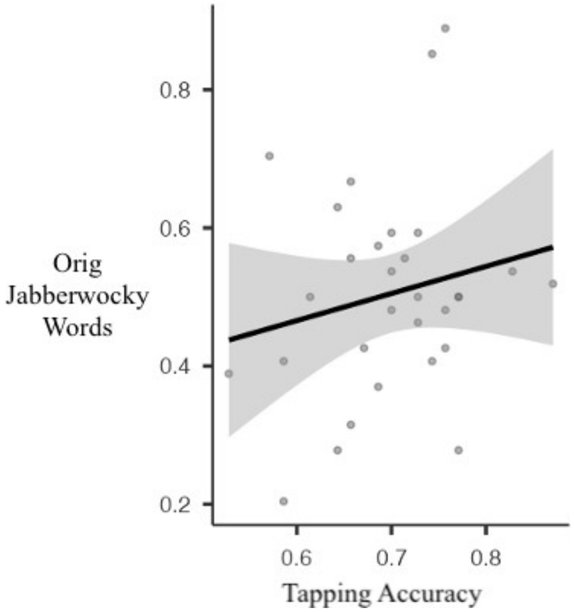


Figure 3

Correlation plot between the Rhythm Task and proportion of correct syllables with Jabberwocky Sentence Task with Switched Prosody (New Prosody Jabberwocky Sylls)

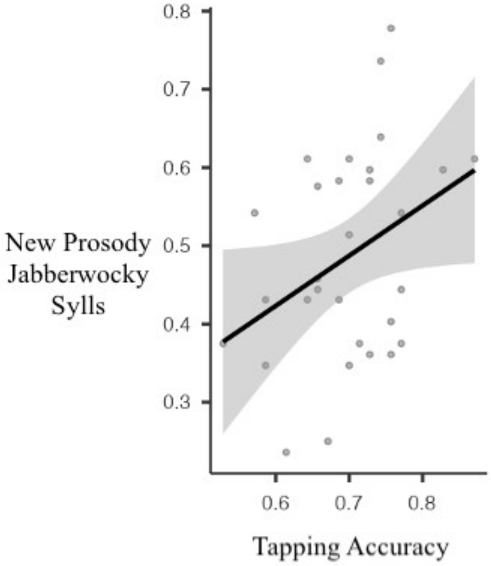


Figure 4

Correlation plot between the Rhythm Task (Tapping Accuracy) and proportion of attempted words in the Jabberwocky Sentence Task with Switched Prosody (New prosody Jabberwocky words)

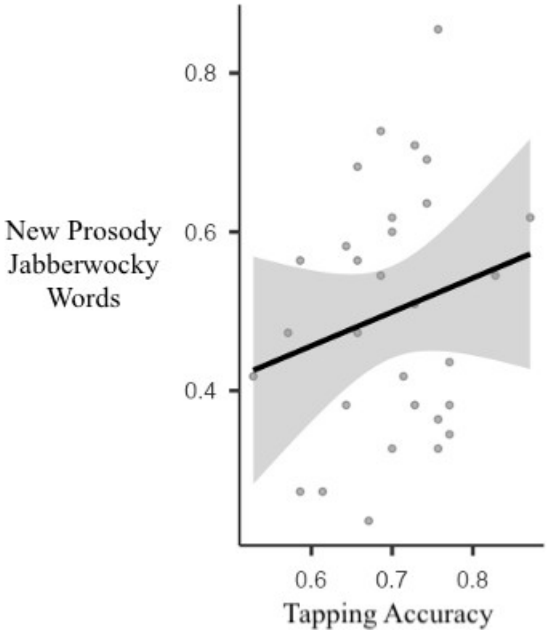


Figure 5

Correlation plot between the Rhythm Task (Tapping Accuracy) and proportion of correctly repeated syllables in the Tamil Sentence Task.

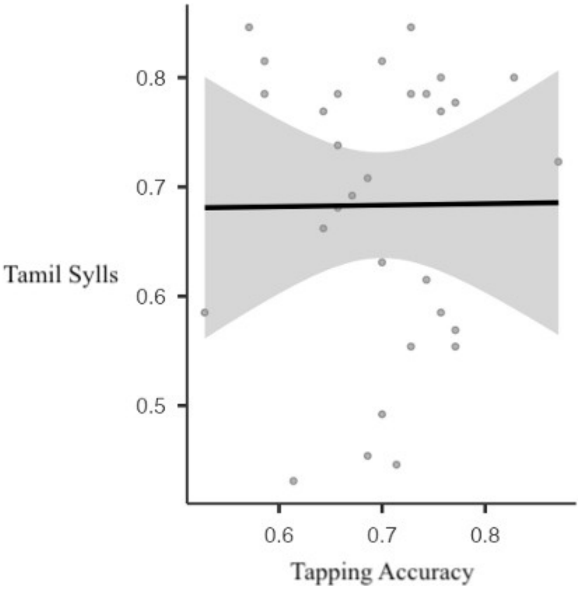
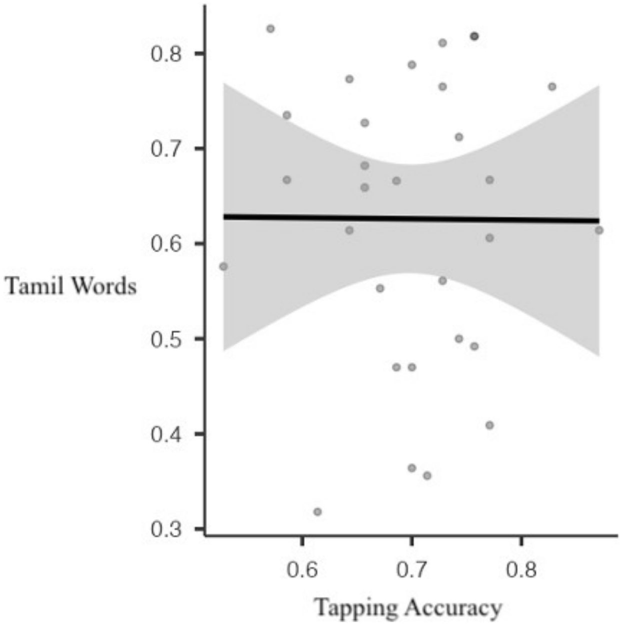


Figure 6

Correlation plot between Rhythm Task (Tapping Accuracy) and proportion of correctly repeated words in the Tamil Sentence Task.



APPENDIX - FINAL STIMULI

English Jabberwocky Sentences- Original Prosody

1. KAY HUS EMENTED IM KILPH
2. KADE GILPERNS KARNAYED ROO WUPS
3. OH DREG PRILED OT ROO BLANTIS
4. ROO FLOGIN JANED IM OH KINTO
5. KAY DUCTORMS PRI CALLS IM THORK
6. KADE CALB GRAMUSHED MO FLOYANS
7. MO GOMER SHILLERS JISH OH PURB
8. WOO TOOGITS VLUX IM ROO NORP
9. JISH FRANCHINESS VEGS PEEB SAMPING
10. KAY ROVLE GILKED WOE RETODES

English Jabberwocky Sentences- New Prosody

1. WOE JIDED UPLING MO NAFF
2. ROO BEACHLORN KAY SWEENS NEDRIL
3. WOE PRUSED VOTION JISH OH ENTSIAN
4. OH TOMASHED MUZE MO FLOOKMUN
5. TAFFERS PEEB SURFEWED ROO ZYPTS
6. KADE CONDLES ADLOOT KAY DUT
7. ROO SUBSITTED GLOB IM OH GAST
8. WOE GEPLER OT SEVITS ROO QUAWN
9. ROO MUDGED GOOKIE IMM OH ROUNCE
10. KAY SEFT SIPPERT JISH ROO GAUM

Tamil Sentences

1. [அ"ன$% தன$ பகர*]

   Arnish tani pakaran
   Arnish is looking at the water.
2. [ஜெக* மேல போனா*]

   Jagan mele ponan
   Jagan is going upstairs.
3. [ஜெயா பாட கேகர3]

   Jaya pata kekeral
   Jaya is listening to a song.
4. [த*வ5 இ7கே வரா8]

   Dhanvi inge varal
   Dhanvi is coming here.

5. [நா:;< %=தி ப5J;<@]
   Naiku Shruthi pidikum
   The dog likes Shruthi.
6. [ராA வ5B;< போறா*]
   Raj vitu ku poran
   Raj is going home.
7. [Sambar romba eriyum]
   The sambar is too spicy.
8. [நா* பJ;க போறே*]
   Naan parika poren
   I am going to study.
9. [கபா3 ல ரொ@ப Dட@]
   Kapal la romba kutam
   The ship is too crowded.
10. [திEதி கீரே போர3]
   Dipti keere poral
   Dipti is going downstairs

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Investigating Auditory Processing in Chronic TBI Patients: Exploring Mismatch Negativity

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Introduction

This project investigated auditory processing differences between healthy individuals and those with chronic Traumatic Brain Injury (TBI) using the Mismatch Negativity (MMN) response. TBI can occur when an external force causes the brain to move within the skull, resulting in changes in cognitive and behavioural functioning (Kaipio, 2016). Damage from TBI can be classified as mild, moderate or severe/chronic, and this classification depends on a variety of factors such as the patient's Glasgow Coma Scale, length of loss of consciousness, alteration of consciousness/mental state, post-traumatic amnesia, and the Injury Severity Scale (Kaipio, 2016). The severity level of TBI can manifest as either acute or chronic, which refers to the different stages or phases of injury and recovery (Kaipio, 2016). In this context, acute refers to the immediate phase following a TBI, and chronic refers to the long-term consequences (Kaipio, 2016). This paper will focus on chronic TBI (cTBI) patients.

Common neuropsychological impairments following TBI include compromised attention, memory functions, and information processing capabilities, as well as challenges in regulating emotions and behaviours (Kaipio, 2016). Auditory processing deficits are reported less frequently in studies despite their significant impact and prevalence among TBI patients. During the chronic stages of injury, individuals with TBI have demonstrated brain volume loss and diminished white matter integrity (Bendline, 2008). White matter serves as the structural basis for neuronal communication between different brain regions, playing a crucial role in language processing as it marks interconnected pathways essential for semantic-lexical and phonological processing (Shekari, 2023). TBI may disrupt the central auditory pathways responsible for integrating auditory information and the auditory cortex, which can affect not only auditory processing but also overall cognitive function (De Godoy et al., 2022). The severity of these deficits can vary widely based on the extent and specific location of the brain injury, rendering TBI a complex condition with a broad spectrum of auditory outcomes.

A study by White et al. (2022) found that 60% of patients with severe TBI exhibited abnormal results on degraded speech tests, including compressed and echoed speech and in filtered conditions amidst background noise. Additionally, 25% of patients displayed a loss in high-frequency hearing (White et al., 2022). Cavanaugh et al. (2019) found that chronic TBI patients showed reduced P3b amplitudes (a component of Event-Related Potentials (ERPs) that reflect cognitive categorization and context updating) to deviant tones presented in a three-stimulus oddball paradigm. Other studies have reported deficits in speech comprehension, localization, auditory discrimination and temporal processing (the brain's ability to perceive and process information presented over time) (Honan et al., 2015; Mioni et al., 2015). While these studies provide evidence suggesting that TBI can lead to auditory processing deficits, the exact mechanisms underlying these deficits are not entirely understood.

One way to examine auditory processing deficits associated with TBI is by examining Event-Related Potentials (ERPs) using an electroencephalogram (EEG). ERPs, derived from EEG recordings, are averaged electrical responses to many presentations of a stimulus and can provide insights into the processing of auditory information in the brain (Garrido et al., 2009). Mismatch Negativity (MMN) is a component of ERPs that occurs when the brain detects a change in sound, demonstrating its ability to recognize and process differences in consecutive auditory stimuli (Garrido et al., 2009). MMN is considered to be an indicator of automatic, pre-attentive processing, as it is recorded when a participant's attention is actively directed away from the stimuli being used (Garrido et al., 2009).

In experimental conditions, MMN is considered to be maximal between 100 to 250 ms across the frontal and central scalp areas after a sound change has occurred (Garrido et al., 2009). Since MMN requires a stimulus change in order to be elicited, oddball paradigms are preferential. These paradigms use repetitions of a standard stimulus that is occasionally replaced by a deviant, which differs in frequency, intensity or phonological properties (Garrido et al., 2009). MMN is thought to result from a comparison between a new deviant stimulus and a memory trace formed by the standard, demonstrating the brain’s ability to store and compare sensory information over time (Cheour et al., 2000). By varying the interstimulus interval between the standard and deviant, researchers can determine the time span of auditory sensory memory (Cheour et al., 2000). If the deviant stimulus occurs while the memory trace of the standard is still active, automatic change detection is activated, eliciting an MMN response (Cheour et al., 2000). Therefore, MMN studies can provide insights into the temporal dynamics of auditory sensory memory, indicating the duration for which the brain retains modality-specific information (Cheour et al., 2000). While some studies have examined MMN in individuals with TBI and demonstrated reduced MMN responses compared to healthy controls (Kaipio, 2016; Sun et al., 2015), they often treat TBI as a homogeneous group, overlooking differences in the severity or stage of recovery. Given the heterogeneous nature of TBI, analyzing MMN responses in specific subgroups, such as cTBI patients, can provide insights into how auditory processing deficits may manifest based on their specific stage of recovery.

Assessing auditory comprehension skills, particularly in TBI, can be challenging and may not accurately identify the levels of processing affected due to cognitive impairments associated with TBI. Traditional testing methods tend to rely on behavioural responses, which can be burdensome for some patients. Therefore, the non-taxing nature of MMN testing, which reflects unconscious processing, makes it a valuable alternative for understanding the neural mechanisms underlying impairments in speech perception.

Considering the auditory processing deficits that have been reported, it was hypothesized that individuals with cTBI would have reduced MMN response amplitudes to the deviant tones presented in an oddball paradigm compared to healthy controls.

Methods

EEG Dataset and MMN Rationale

This project utilized an existing raw EEG dataset from a study conducted by Cavanaugh et al. (2019). The dataset was obtained from OpenNeuro, which provides a platform for researchers to share the data they have obtained with others. The researchers in the original study examined the amplitudes of the P3 component. They found that cTBI patients with higher symptoms had lower P3 amplitudes but did not find differences between the cTBI patients and the controls (Cavanaugh et al., 2019). The P3 component is most commonly elicited in response to a low probability or deviant stimulus, similar to MMN. While deviant stimuli can elicit both P3 and MMN, they arise from different cognitive processes and have distinct characteristics: P3 peaks around 300 ms and reflects higher-order cognitive processing related to attention, context updating and memory retrieval, whereas MMN peaks around 100 to 250 ms and reflect pre-attentive and automatic change detection of sensory deviance (Cavanaugh et al., 2019; Garrido et al., 2009). Although the P3 response component can be elicited by various sensory modalities, including auditory stimuli, its occurrence is not limited to auditory processing (Cavanaugh et al., 2019). Since MMN is a more direct measure of auditory discrimination and change detection processes, it may be more sensitive to disruptions in auditory processing pathways resulting from TBI-related injuries. Therefore, this project examined MMN response amplitudes in the same participants to see if changes related to cTBI were reflected in this earlier, pre-attentive ERP component.

Participants

The original study included a total of 96 participants, including controls (n = 24), mild TBI (mTBI) patients (n = 38) and cTBI patients (n = 23) (Cavanaugh et al., 2019). This project compared the data of the controls to the cTBI patients, leaving 39 participants, 19 of whom were cTBI patients, and 20 were controls. 3 controls and 4 cTBI patients were excluded due to noisy data. The study focused on cTBI patients because they often present with more pronounced and persistent deficits compared to mTBI (Kaipio, 2016). By focusing on cTBI, the project aimed to investigate the long-term effects of TBI on auditory processing

All participants in the study were between 18-55 years old, fluent in English, had no premorbid major medical or psychiatric conditions and had no current or previous history of substance abuse (Cavanaugh et al., 2019). The inclusion criteria used for the cTBI patients were: experienced a loss of consciousness for less than 24 hours, Glasgow Coma Scale of 9-15, less than one week of post-traumatic amnesia and endorsed as least one ongoing cognitive symptom on the Neurobehavioral Symptom Inventory (Cavanaugh et al., 2019).

Auditory Oddball Task

The original study by Cavanaugh et al. (2019) employed a three-stimulus auditory oddball task consisting of three tones: standards were 440 Hz sinusoidal tones (70% of trials), targets were 660 Hz sinusoidal tones (15% of trials), and novel distractors (15% of trials) from a naturalistic sounds dataset. In this task, both the target and novel distractor stimuli act as auditory deviants, however, they differ in their characteristics and functions within the task. The target tones adhere to the expected pattern of auditory stimuli but differ in frequency from the standard tones, thus serving as one type of deviant. In contrast, the novel distractor stimuli diverge from the established auditory pattern by introducing a set of acoustic emotional stimuli commonly utilized in studies of emotion and attention (Bradley & Lang, 1999). These novel distractors disrupt the anticipated auditory pattern of "tones," acting as an alternative deviant.

The sounds were presented for 200 ms at 80 dB with a random inter-trial interval of 1000 to 1500 ms. There were a total of 260 trials for each participant: 184 standard, 38 targets, and 38 novels.

EEG Recording and Preprocessing

Cavanaugh et al. (2019) conducted EEG recording using a 64-cap Ag/AgCl electrode system, capturing signals with a frequency range of 0.1 to 100 Hz and a sampling rate of 500 Hz.

For this project, the data were preprocessed using the EEGLab and ERP toolboxes (Delorme & Makeig, 2004; Lopez-Calderon & Luck, 2014) in MATLAB, with some modifications to the preprocessing steps used in the original study. The ventral electrooculogram (VEOG), electrocardiogram (EKG) and four ventral temporal channels near the ears were removed, leaving 60 electrodes. Bad channels were identified using the channel spectra maps function from EEGlab and were interpolated. The data was referenced offline to the CPz electrode. The data was filtered to remove frequencies outside the range of 0.1 Hz to 20 Hz, and the mean value DC bias was removed. ERPs were computed for epochs spanning from 200 ms before stimulus onset to 800 ms after stimulus onset, with baseline corrected from -200 to 0 ms pre-stimulus. Trials contaminated with eye movements/blinks were identified using Independent Component Analysis (ICA), where bad components were identified visually and removed. Any remaining artifacts were removed using Automatic Artifact Rejection with a simple voltage threshold of -100 to 100. Individual averaged ERPs were generated for each participant and condition. **Figure 1** shows the grand averaged ERPs across participants for the control and cTBI groups. The MMN response is considered to be the difference between the standard stimuli and the deviant. Two difference waves were created by subtracting the standard from the target and the standard from the novel distractors. The difference waves were averaged across the frontal and central electrodes (Fz, F1, F2, F3, F4, FCz, FC1, FC2, FC3, FC4, Cz, C1, C2, C3, C4), and the mean amplitude in the 100 to 250 ms time window was extracted for each participant and condition.

Statistical Analysis

A mixed-effects model was employed to test for fixed effects of group (control or cTBI), deviant type (target or novel) and their interaction. The model evaluated whether MMN response amplitudes differed significantly from zero within conditions (i.e., presence of MMN response) and between groups (i.e., dissimilar MMN response patterns between controls and cTBI patients). Additionally, interactions between deviant type (target or novel) and group (control or cTBI) were tested. Significance levels were determined based on estimated coefficients and associated p-values.

Results

Presence of MMN Response

For the control group, a significant effect was observed for the MMN response amplitude for the target stimulus (p = 0.005) **(Figure 2)** and for the novel distractor stimulus **(Figure 3)** (p = 0.006). For the cTBI group, no significant effects were observed for the MMN response amplitudes for either stimulus (see Figure 2 for Target and Figure 3 for Novel; Target: p = 0.247, Novel: p = 0.597).

Group Differences in MMN Response

No significant effects were observed between the control and cTBI groups for the target stimulus (see **Figure 2**; p = 0.295) or the novel distractor stimulus (see Figure 3; p = 0.287).

Effect of Deviant Type

For the control group, a significant difference was observed between the MMN response amplitude for the target stimulus and the novel distractor stimulus (p = 0.008) (Figure 4). For the cTBI group, no significant effect was observed between the MMN response amplitude for the target stimulus and the novel distractor stimulus (p = 0.254).

Discussion

This project investigated auditory processing differences between healthy individuals and those with cTBI using the MMN response. The findings shed light on the complexities of auditory processing deficits in individuals with cTBI and contribute to our understanding of the neural mechanisms underlying these deficits.

The results revealed a significant effect for the MMN response amplitude within the control group observed to both the target and novel distractor stimuli. This is consistent with previous findings demonstrating intact pre-attentive auditory processing in healthy individuals (Garrido et al., 2009). However, in individuals with cTBI, no significant MMN response to either stimulus type was observed. Despite the lack of evidence for the MMN in the cTBI group, no significant differences were observed between MMN amplitude for the cTBI and control group for either stimulus type. The absence of group differences may be attributed to heightened noise levels within the TBI group. A larger sample size would be needed to ascertain whether the observed pattern in the plots reflects a real effect. Nevertheless, this pattern and visual speculation still suggest that cTBI patients exhibit attenuated MMN response patterns compared to the controls. This would be consistent with the notion that TBI can disrupt auditory processing, likely due to structural and functional alterations in the brain, including compromised white matter integrity and neuronal communication pathways (De Godoy et al., 2022; Shekari, 2023). These results support the findings of previous studies that found that those with TBI had reduced MMN responses compared to healthy controls with deviant tones (Kaipio, 2016; Sun et al., 2015).

The investigation into the MMN response to different types of deviants found that in the control group, there were significant differences between MMN amplitude for the deviant and novel distractor stimuli. This suggests that the control group successfully differentiated between the two deviants (Garrido et al., 2009). In contrast, no significant difference was found in the MMN response amplitudes between the type of deviant used for the cTBI group despite a visual difference being observed. Again, a larger sample size would be needed to confirm if what is observed in the plots reflects a real effect. However, no significant difference between the two types of deviants implies a potential deficit in discriminating between them for the TBI group. This suggests that TBI may interfere with auditory discrimination abilities, resulting in difficulty in distinguishing subtle differences between various auditory stimuli (De Godoy et al., 2022).

Interestingly, the MMN response patterns were extremely different between the two deviants, the one for the target being negative and the one for the novel distractors being positive in both groups. As seen in Figure 5, EEG activity for the target stimuli clusters toward the front of the scalp, while for the novel distractor stimuli, clusters are seen more toward the back. The contrasting MMN response patterns may reflect differing cognitive processes involved in detecting the target stimuli compared to the novel distractors. While this aligns with previous research demonstrating the brain's sensitivity to diverse auditory features and its ability to distinguish between different types of deviants (Garrido et al., 2009), the exact factors underlying the occurrence of a positive or negative MMN response remain unclear and require further investigation.

Although there were visually and numerically suggestive differences in MMN responses between cTBI patients and controls, these differences did not reach statistical significance. It is worth noting that similar non-significant findings between the two groups were reported in the original study investigating P3 response amplitudes. These inconclusive findings may stem from a range of factors, including sample size limitations, heterogeneity within the cTBI patient group, or variability in the severity and nature of TBI-related deficits. These limitations could have contributed to the lack of statistically significant differences in the P3 and MMN components.

For future studies, exploring potential subgroup differences with the cTBI and mTBI populations, such as based on injury severity, time since injury, or specific cognitive impairments, could help identify distinct profiles of auditory processing deficits. While significant differences were not observed between the cTBI group and controls, it would be interesting to explore whether disparities exist in MMN response patterns between the mTBI and control group. Furthermore, integrating neuroimaging techniques such as functional magnetic resonance imaging (fMRI) or diffusion tensor imaging (DTI) with EEG/ERP measures could offer a more comprehensive understanding of the neural correlates underlying auditory processing deficits in cTBI. Investigating structural and functional alterations in auditory-related brain regions may provide insights into the pathophysiology of these deficits and inform targeted therapeutic approaches. Lastly, conducting longitudinal studies to track changes in auditory processing over time following TBI would provide valuable insights into the progression of deficits and their impact on functional outcomes. By examining auditory processing at multiple time points post-injury, researchers can elucidate the trajectory of recovery or deterioration and identify critical periods for intervention.

Conclusion

In conclusion, the findings of this project have the potential to shed light on how TBI affects auditory processing, specifically focusing on the MMN response to deviant tones. By investigating MMN alterations in individuals with chronic TBI compared to healthy controls, this research aims to contribute to our understanding of the neural mechanisms underlying auditory deficits in TBI. This could have implications in establishing MMN alterations as a marker of TBI, where MMN could serve as a non-invasive tool for assessing auditory processing deficits in TBI patients, aiding clinicians in diagnosing and monitoring the condition. Additionally, understanding MMN patterns associated with TBI may help predict language outcomes and cognitive recovery trajectories in affected individuals where improvements in the MMN response over time could be associated with recovery. Overall, this project highlights the potential of MMN as a valuable biomarker for assessing cognitive function in individuals with TBI-related auditory impairments.

TABLES & FIGURES

Figure 1

Grand average event-related potentials across all electrodes for controls and cTBI.

The black waveform is the standard stimulus (Bin 2), red is the target (Bin 2), and blue is the novel distractor (Bin 3). The x-axis for each electrode is the time (ms), and the y-axis is the potential (uV).

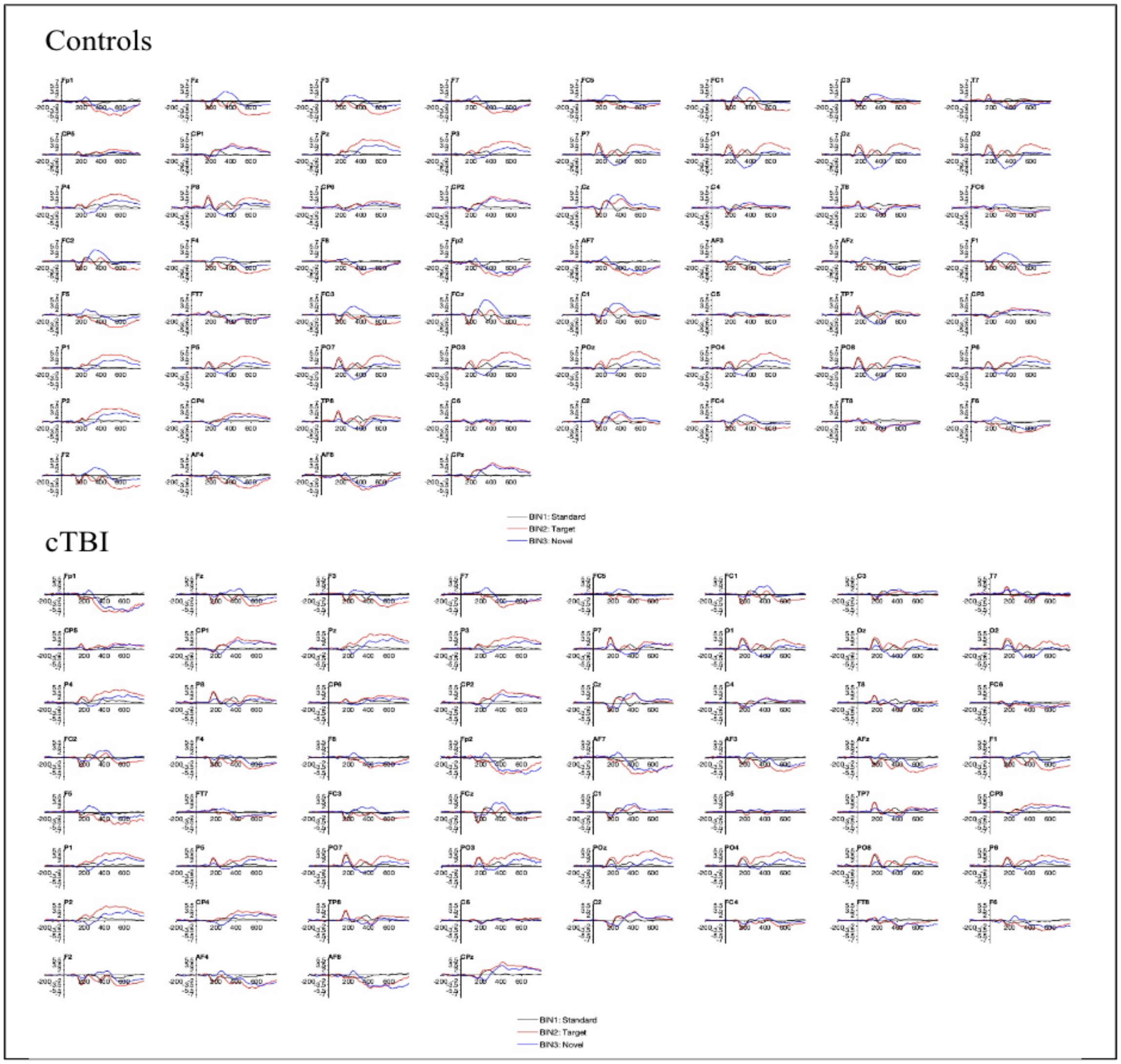


Figure 2

Average difference wave for the target stimuli at the FCz electrode comparing the MMN response between the controls and cTBI patients.

MMN was defined as the average amplitude between 100 to 250 ms after stimulus onset, as shown by the red box. Only the controls showed a significant effect on MMN amplitude. The x-axis is the time (ms), and the y-axis is the potential (uV). Ns = not significant. *p<0.05.

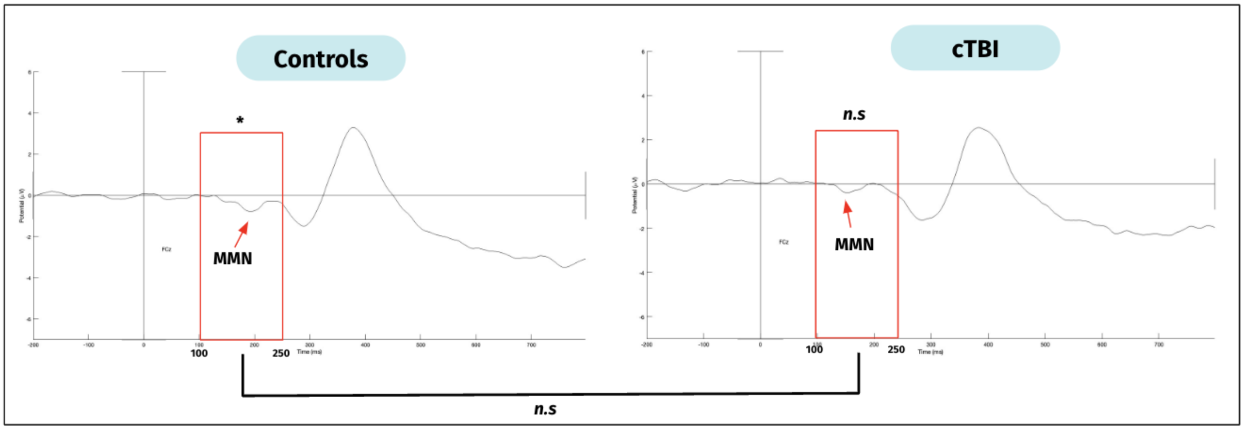


Figure 3

Average difference wave for novel distractor stimuli at the FCz electrode comparing the MMN response between the controls and cTBI patients.

MMN was defined as the average amplitude between 100 to 250 ms after stimulus onset, as shown by the red box. Only the controls showed a significant effect for MMN amplitude. The x-axis is the time (ms), and the y-axis is the potential (uV). Ns = not significant. *p<0.05.

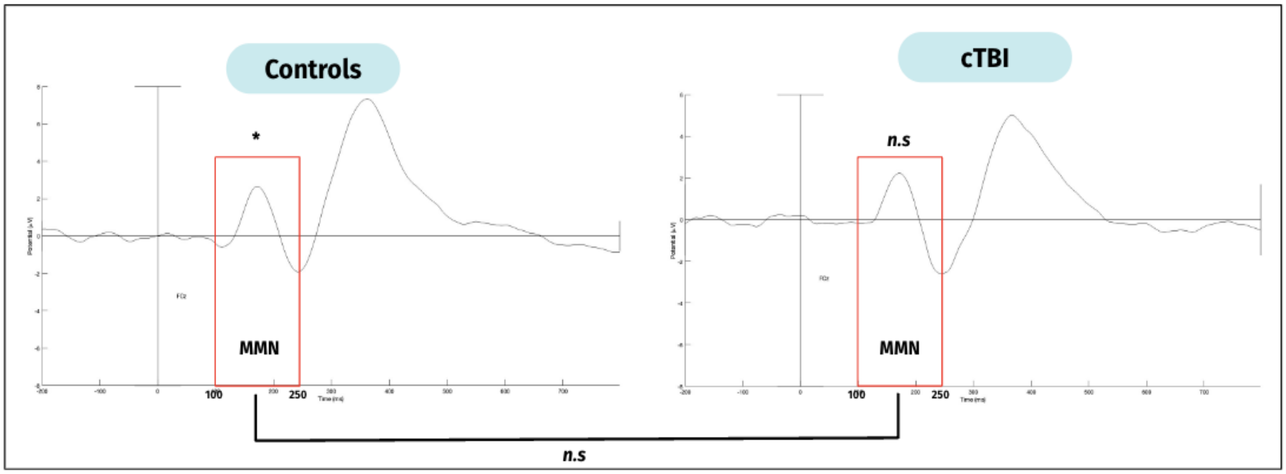


Figure 4

Average difference waves for the target and novel distractor stimuli at the FCz electrode comparing the differences between the type of deviant used for the controls and cTBI patients.

MMN was defined as the average amplitude between 100 to 250 ms after stimulus onset, as shown by the red box. Only the controls showed a significant effect for the type of deviant used. The x-axis is the time (ms), and the y-axis is the potential (uV). Ns = not significant. *p<0.05.

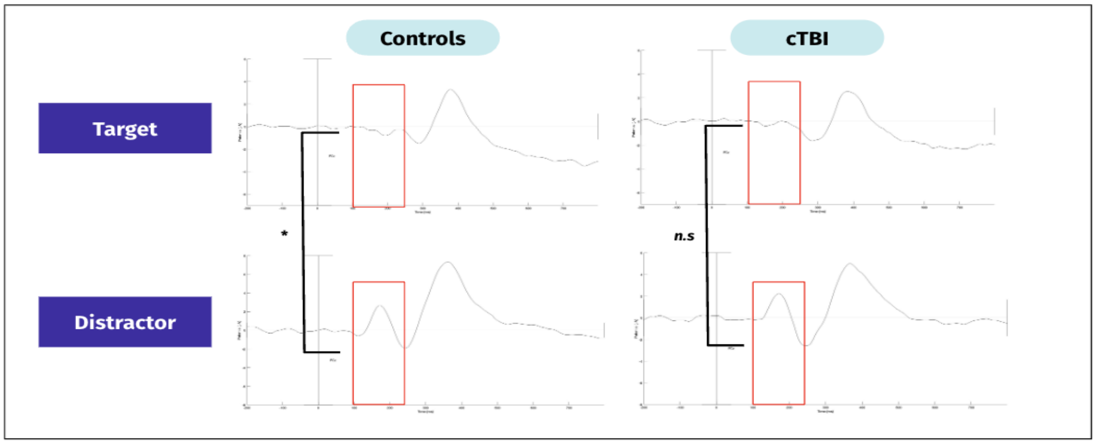
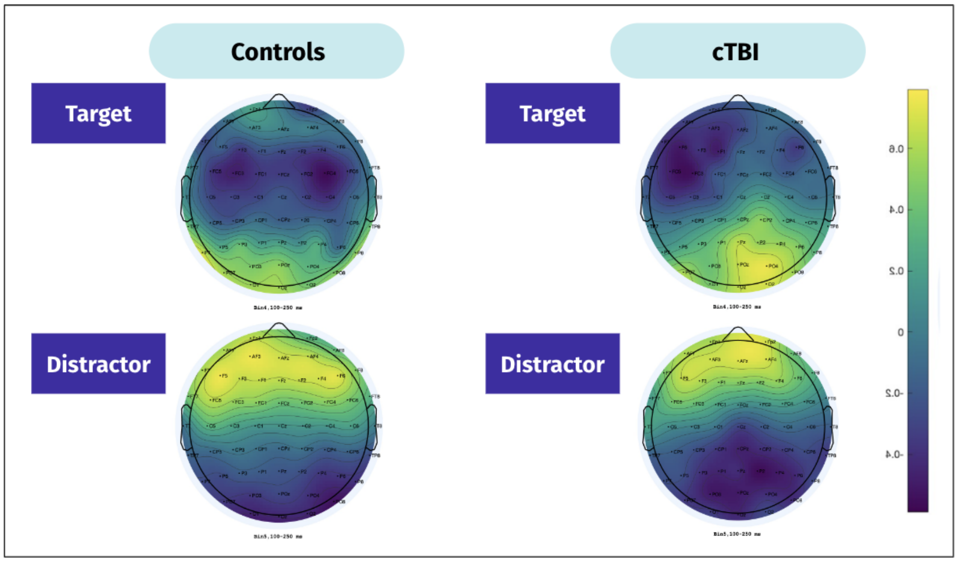


Figure 5

Averaged event-related potential scalp plots for the cTBI and control groups.

The plot displays activation pattern differences between the two groups and between the type of deviant used during the MMN time window. The MMN time window was defined to be 100 to 250 ms.



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Bridging the Gap: The Importance of Outreach Initiatives in Research

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In conducting scientific research, the methods we use are just as important as the questions we ask. At ARiEAL, we have access to a variety of cutting edge technologies. Our EEG, ultrasound, and eye-tracking equipment allow us to explore the fields of language and cognition from multiple angles and approaches. However, these methods are not without their limitations. In fact, each technology comes with its own set of constraints, often excluding certain populations or yielding biased data. These methodological barriers reveal the importance of refining our experimental tools to ensure the research community remain inclusive to the diverse populations we study. To address obstacles, it is crucial to recruit researchers who can identify and address these issues with cultural and scientific understanding. This article examines the impact of targeted outreach initiatives designed to engage underrepresented communities in the field of language sciences.

The methodological barriers posed by research equipment are not abstract challenges—they can be seen right here at ARiEAL. Despite having access to state-of-the-art technologies like ultrasound, EEG, and eye-tracking, we face unique limitations that directly affect our ability to gather inclusive data. Dr. Daniel Pape's Phonetics lab at ARiEAL uses ultrasound technology to analyze tongue movement and position to find differences in participant speech production. However, facial beards are a barrier to ultrasound waves, limiting the participant pool to individuals without prominent facial hair (NHS, 2023). Currently, there is no practical or ethical solution to this problem that does not involve asking participants to remove their facial hair. This limitation may inadvertently lead to us collecting data primarily from a limited population of female-presenting individuals without facial hair. As a result, we risk missing critical data that could contribute to a more comprehensive understanding of speech production across diverse groups, reducing our ability to generalize findings to whole populations.

Next, ARiEAL's access to EEG equipment is one of our most impressive technologies, used in multiple labs across the research centre. Unfortunately, EEG contributes to significant racial bias within the scientific community, particularly impacting Black individuals' representation in neuroscientific research data (Louis et al., 2022). This exclusion stems from the assumption that Black hair, specifically Black hairstyles, leads to poor data quality, causing researchers to actively screen out individuals who do not have straight or wavy hair types (Wolny, 2022). The natural characteristics of African hair types can interfere with EEG caps and electrodes making direct contact with the scalp, which is essential for recording brain activity (Choy et al., 2022). Though some efforts towards a solution have been made, such as redesigning the electrodes' shape and materials, no real resolution has made its way into mainstream EEG practices (Choy et al., 2022).

ARiEAL's director, Ivona Kucerova, advocates for discarding such methodologies altogether and pushing for funding for alternative technologies like MEG as these limitations are not relevant in MEG technology. Until we can receive funding for alternative technologies, we must recruit researchers who can address these problems with an intimate understanding of both culture and science. For example, Yaqian Bao from the ARiEAL Reading Lab is transforming eye-tracking technology to support written scripts with vertical orthography in East Asian writing systems. Bao identified a gap in reading research, noting that the majority of data was coming from English language studies.

In fact, she could not find any publications where eye-tracking technology was successfully adapted for non-horizontal reading scripts. As a Mongolian speaker, Bao recognized the need to modify eye-tracking technology for the unique writing systems present in her community. In a short interview, she discussed how a previous attempt by a non-East Asian researcher who did not speak any languages with vertical writing systems faced numerous problems, rendering the data useless. Such anecdotes emphasize the importance of diversity among researchers. Bao's cultural and scientific investment in her project aims to attract the scientific community's attention to Mongolian as an endangered language. Bao asserts, "We need to encourage people from these underrepresented communities because they understand the languages and cultures and can truly represent their community in the research field."

To address such methodological gaps, it is crucial to recruit researchers who can identify and address these issues with cultural and scientific understanding. In partnership with the MacPherson Institute, ARiEAL trainees orchestrated a series of interactive workshops where students visited the research labs to gain exposure to language science research practices. The students were recruited from iSTEP, a STEM enrichment program for Black High School students in the Hamilton and Halton area. McMaster iSTEP Outreach Director, Renee Boney, helped organize this partnership between ARiEAL and iSTEP because she "believe[s] that outreach initiatives make a real change. Students get the opportunity to explore their education options and actively see that there is space for them in many different fields".

The outreach workshop was conducted in two parts. The first part of the workshop introduced students to Cognitive Science of Language, and various STEM methodologies involved in the research. Students interacted with EEG, ultrasound, eye-tracking, and the methods' applications in the language sciences, gaining a general understanding of linguistics research. A few months later, the students returned for the second part of the workshop, where they conducted a real EEG experiment. This workshop was focused on understanding the scientific method of EEG, running real experiments, and analysing results. This workshop also intimately addressed the issues with EEG and Black representation, where the iSTEP students experienced first-hand how EEG exclusion criteria impacts their community. The students provided thoughtful feedback, recognizing that such exclusion removes their community's representation from research data, which in turn limits the applicability of that data in addressing their needs.

Together, iSTEP students brainstormed different solutions, such as adapting the shape of EEG electrodes to adapt to Black hairstyles, and different hair styling techniques that could be compatible with the technology. The students also discussed how racial biases should be addressed by researchers, not the community. For example, asking someone to shave their head for the purposes of EEG is unethical, though it was a suggestion that came to their minds. In a post-workshop survey, one student mentioned that the workshops helped open their eyes to how there is "less language science research [data] in [the] black population due to inaccessibility". Another Grade 11 student said that discussing ways to improve racial and hair type bias was the most valuable part of their workshop experience. Our results demonstrate that outreach initiatives provide students with the space to discuss and brainstorm different areas of science. The ARiEAL Outreach Program was a useful tool to engage future students with language sciences. In fact, across all the workshops, 40% of the students identified that the program helped increase their interest in the language sciences.

In conclusion, the ARiEAL Outreach Program has demonstrated the profound impact that targeted initiatives can have on engaging underrepresented communities in the field of language sciences. By providing interactive workshops that not only introduce students to cutting-edge research methodologies but also address critical issues of inclusivity and representation, we can inspire a new generation of researchers who are both culturally and scientifically informed. Feedback from the students underscores the importance of diversity in research, highlighting the need for ongoing efforts to make our methodologies accessible to all. From a scientific perspective, diversity leads to richer, more comprehensive data that can enhance the validity and applicability of our findings across populations. As we continue to advocate for better funding and more inclusive technologies, it is clear that such outreach initiatives are essential for fostering a more diverse and representative scientific community. The success of these workshops not only increases interest in language sciences but also paves the way for more equitable research practices, ultimately enriching the field with varied perspectives, deeper insights, and greater scientific impact.

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McMaster University

BRIGHTER WORLD

Proposal: Exploring Code-Switching in Trilinguals: An EEG Investigation of Language Dominance and the N400 response in English-French-German speakers

HUMANITIES
Linguistics
& Languages

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Introduction

- Research shows that bilinguals require **more effort to switch into a non-dominant language** than the other direction. [1]
- This switching produces an **N400 effect.** It remains unclear if the same effect is true for trilinguals.
- The **N400 effect** occurs when the participant encounters unexpected stimuli. It is captured through EEG (electroencephalogram).

Research questions

Which direction of code-switching elicits the biggest N400 response in trilinguals?

Do trilingual participants show the same N400 activations in code-switching as bilingual participants?

Expected results

- It is expected that trilinguals will exhibit the largest N400 effect when switching from their two dominant to non-dominant languages. This is consistent with data from billinguals.

Participants

- Participants are 30 students from the University of Strasbourg, France, who all have the same level of fluency and dominance.
- French native (L1), English fluent (L2), German beginner to intermediate (L3). French and English are the participants dominant language, whereas German is the weak language.
- Participants are frequent French-English code-switchers in an understudied trilingual linguistic community.

Experimental Design

- An online EEG **story time task** [2] with a within-participants design**.**
- Participants listen to a story where code-switching can occur on the **sentence-final word.** The code-switched word is either an **expected (plausible) or unexpected word (implausible).**
- Participants are unaware as to which sentences in the story will contain a code-switch. The goal is to compare **N400** activation in code-switched and non code-switched sentences, as well as the impact of the language pairing/relationship between plausible and implausible stimuli.

Key measures

- An **N400** response is predicted at the time of the code-switch. This shows an indication of lexical access difficulty. More specifically, the amplitude and latency of the signal will be recorded.
- **Frontal negativity** (negativity in frontal regions of the scalp) is expected to be seen. This indicates the inhibition of the dominant language and provides better prediction of the upcoming word.

Plausible Stimuli

Translation: (I drink my coffee with cream and sugar)

French → English
Je bois mon café avec de la crème et du ***sugar.***

French → German
Je bois mon café avec de la crème et du ***Zucker.***

Implausible Stimuli

Translation: (I drink my coffee with cream and dog)

French → English
Je bois mon café avec de la crème et du ***dog.***

French → German
Je bois mon café avec de la crème et du ***Hund.***

Analysis

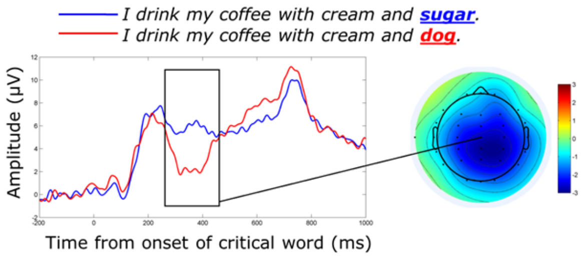

Figure adapted from Hunt, Politzer-Ahles, Gibson, Minai, & Fiorentino (2013)

Figure 1: This figures shows a diagram illustrating the N400 response with two example sentences. [3]

Languages	BIN 1: PLAUSIBLE STIMULI (Amplitude)	BIN 2: IMPLAUSIBLE STIMULI (Amplitude)
CODE SWITCHED		
L1 (French) → L2 (English)	ex. 300mv	ex. 300mv
L1 (French) → L3 (German)		
L2 (English) → L1 (French)		
L2 (English) → L3 (German)		
L3 (German) → L1 (French)		
L3 (German) → L2 (English)		
NON-CODESWITCHED		
L1 (French) → L1 (French))	ex. 300mv	ex. 300mv
L2 (English) → L2 (English)		
L3 (German) → L3 (German)		

Figure 2: This table represents how the experiment will be split into three trials, French story, English story, and German story. The language on the right of the arrow is the language that is used for code-switching.

Practical Implications

- Results of this study could influence how multilingual education and work programs using frequent code-switching are designed.

Future Research

- Future investigation into additional variables such as frontal negativity and ERP latency and its impact on the **N400 effect.**
- Future studies that focus on the learning effect or longitudinal design.

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BRIGHTER WORLD

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HUMANITIES
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INVESTIGATING SPEECH MOTOR CONTROL AND PERCEPTION IN AUTISM SPECTRUM DISORDER

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INTRODUCTION

What is Autism Spectrum Disorder (ASD)?

- ASD is a complex neurodevelopmental condition that is characterized by a broad spectrum of abilities, challenges and characteristics.
- Individuals with ASD may face speech and language impairments, impacting their capacity to produce and/or perceive speech [1].

LOW —— HIGH
Autistic Character Traits

Affects of ASD on Speech Production/Perception

- Exhibit **distinct differences in the acoustic features** of their speech such as in pitch, vowel formant frequencies, and intensity [3].
- **Restricted speech motor skills**, affecting tongue and lip functions, may cause **articulation errors in coarticulated words/sentences** [4].

Coarticulation: Neighbouring sounds influence the pronunciation of another speech sound.

- May struggle with **processing speech signals involving higher-order information**, like **categorical perception** [7].
- **Perceptual compensation** for coarticulation may be compromised due to **challenges in attention switching and communication** [5].

Perceptual Compensation: Ability of the perceptual system to adjust for variations in speech sounds.

- Lower accuracy on sound discrimination tasks possibly attributed to a **bias for local processing** over overall context, potentially linked to **weak top-down processing** [7].

Mismatch Negativity (MMN) Response

Electroencephalography (EEG)
- Measures electrical activity of the brain.

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Event-Related Potentials (ERPs)
- Brain responses to specific stimuli/events.

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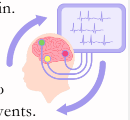
Mismatch Negativity (MMN)
- Brain's sensitivity to sound changes.
- Reflects pre-attentive processing [2].



OBJECTIVE

Investigate co-articulation differences in speech production and speech perception between individuals with low and high autistic character traits.

METHODS

① Perception Task

Identification Task

- **CV stimuli**

Mixtures of /s/ and /ʃ/ + **/a/** or **/u/**

  - 50% /s/ + 50% /ʃ/
  - 65% /s/ + 35% /ʃ/
  - 35% /s/ + 65% /ʃ/
  - 20% /s/ + 80% /ʃ/
  - 10% /s/ + 90% /ʃ/
- **20 repetitions** per mixture: 10 with /a/, 10 with /u/
- **After presentation of each stimulus:**
  - Identify fricative heard /s/ or /ʃ/.
  - Rate confidence.

EEG Session

- **Oddball Paradigm:**
  - Repetitions of standard stimulus infrequently replaced by deviant stimulus.
    - **Standard stimulus:** /s/ with /u/
    - **Deviant stimulus:** 50% /s/ + 50% /ʃ/ with /u/
  - Conducted while **watching a video on silent**.
- **EEG**
  - 64-electrode cap records brain activity.
  - **Identify MMN** response between **100-250 ms** post-deviant stimulus onset [2].

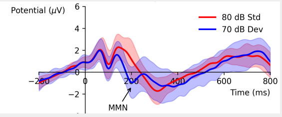


Figure 1. MMN response. From O'Reilly, J. (2021, May 19). Mismatch Negativity. Encyclopedia.pub; Jamie O'Reilly. https://encyclopedia.pub/entry/9812

Participants

- Selection of participants will be based on their **Autism Spectrum Quotient (AQ) questionaire scores.**
- At least **50** right-handed, native English Speakers.

② Production Task

Diadochokinetic (DDK) Task

- Repetitions of **CV syllables**

/s/ and /ʃ/ + **/a/** and **/i/** and **/u/**

- Sets
  - 1. /si, su, sa/
  - 2. /ʃi, ʃu, ʃa/
- **3 trials per initial sibilant.**
- Follow **accelerated metronome**: 60BPM + 10BPM every set.
- **Visualize tongue movements** during speech.
- PRAAT software to **identify spectral components post-production** (pitch, intensity, formant values).

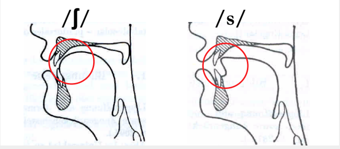


Figure 2. /s/ and /ʃ/ articulation. From Pape, D. (2023). Place and Manner of Articulation of Consonants and Vowels [PowerPoint Slides].

EXPECTED RESULTS

Hypothesis 1:

Those with higher AQ traits will show **greater compensation for coarticulation** with productions closer to /ʃ/ when /s/ is presented in a rounded vowel contexts.

Hypothesis 2:

Those with higher AQ traits will have **lower identification accuracy** of ambiguous phonemes and will show **reduced MMN response amplitudes.**

PERCEPTION/PRODUCTION LINK

- **Exemplar-Based Approach:**
  - Proposes a perception-production loop [6].
  - Perceptual experiences influenced by social, attentional factors, and exemplars [6].
  - Perceptual experiences lead to context-specific production targets [6].

If an individual produces /s/ like /ʃ/ in specific contexts.

↓

They are more likely to perceptually identify an ambiguous phoneme as /ʃ/ rather than /s/ in that same context.

SIGNIFICANCE/CONCLUSIONS

- This project **addresses a critical gap in our understanding of the relationship between motor control, speech production, and perceptual processing** in individuals with autistic traits.
- This study aims to **shed light on challenges faced by individuals with ASD** through differences in speech production and perception.
- By incorporating ultrasound and EEG techniques, it **offers a comprehensive approach** to examining both physical aspects of speech production and neural mechanisms underlying speech perception.
- Overall, this research contributes not only to understanding communication challenges in ASD but also holds promise for advancing broader neurodevelopmental research.

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