Decoding Neural Representations of Sentences in Individuals with Autism

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Introduction

Autism

- Complex neurodevelopmental disorder
- Difficulties in social communication, interaction, and behavior.
- May have difficulties and strengths in various language areas like pragmatics, grammar, semantics, and syntax in both speaking and writing

Understanding Figurative Language

- They have a tendency to interpret statements too literally.
- They may struggle with understanding figurative language.

Functional Magnetic Resonance Imaging (fMRI)

- Non-invasive tool to study brain
- Reflect changes in blood oxygenation levels
- Representation of neuronal activity
- Provides valuable insights into brain function

Main Questions

Does neural activity in the brain carry information about how autistic and non-autistic individuals process figurative language?

How does the process of metaphor processing differ in autistic individuals compared to non-autistic individuals?

Data

Sentences

- 160 sentences
- The sentences follow the structure '*Some x are y*'
  - *x* represents a category name
  - *y* is as an exemplar
- Four categories:
  - Literally True (LT): 80
  - Literally False (LF): 40
  - Metaphors (M): 20
  - Scrambled Metaphors (SM):20

Sentence Categories

- LT:
  - x represents a category name, like "trees"
  - y represents a common exemplar of that category, such as "oaks"
  - Example: "Some trees are oaks"

Sentence Categories

- LF:
  - Created by scrambling the literally true sentences
  - Example: “Some experts are nurses”
    “Some trees are oaks”
    “Some experts are oaks”

Sentence Categories

- M:
  - Have a readily interpretable non-literal meaning
  - Example: Some cats are princesses.

Sentence Categories

- SM:
  - Created by scrambling the metaphors
  - Example: “Some desks are junkyards”
    “ Some hands are magic”
    “Some desks are magic”

Participants

- 12 autistic and 12 non-autistic participants
  - Excluded data from three autistic participants
- Spoke English as a first language
- Passed a hearing screening

Procedure

- Sentences played to individuals with and without autism.
- Participants pressed keys to show if sentences were true or false.
- MRI scanner recorded brain activity during tasks.
- Responses and response times were noted.
- Preprocessed the fMRI signals → Beta weights

ROIs

- Combine voxels from these region into Language-ROI region:
  - Left angular gyrus (AG): semantic processing
  - Left inferior frontal gyrus (IFG): phonological and semantic processing
  - Left dorsal anterior cingulate cortex (dACC): decision-making

Beta Weights Classification

Classification

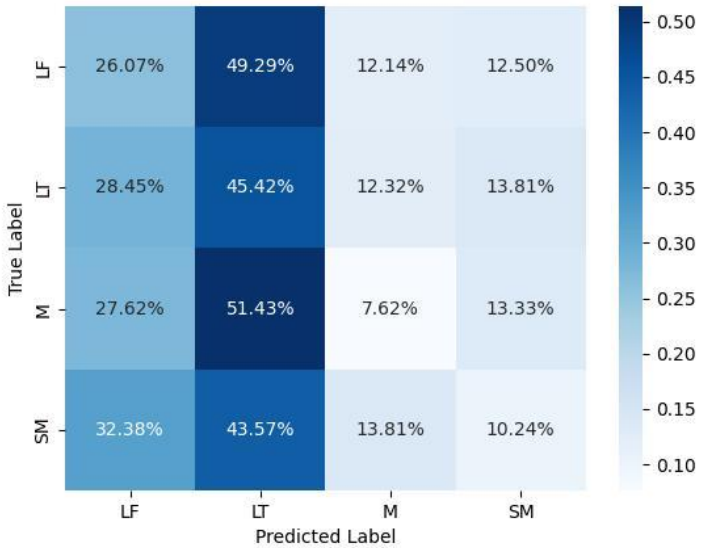
- Scenarios:
  - All four classes: **LT**, **LF**, **M**, and **SM**
  - Two Classes → **LT** and **F**
    → LF, M, and SM grouped as F.

Setup

- Standardization using StandardScaler.
- PCA to explain 85% of the variance in data.
- Handling NaN values:
  - Replace with zero
  - Drop
- Classifiers: Logistic Regression.
- Tuned hyper-parameters using grid search.
- Applied 5-fold nested cross-validation for each subject.
- Maintained the ratio of classes in test/train sets.

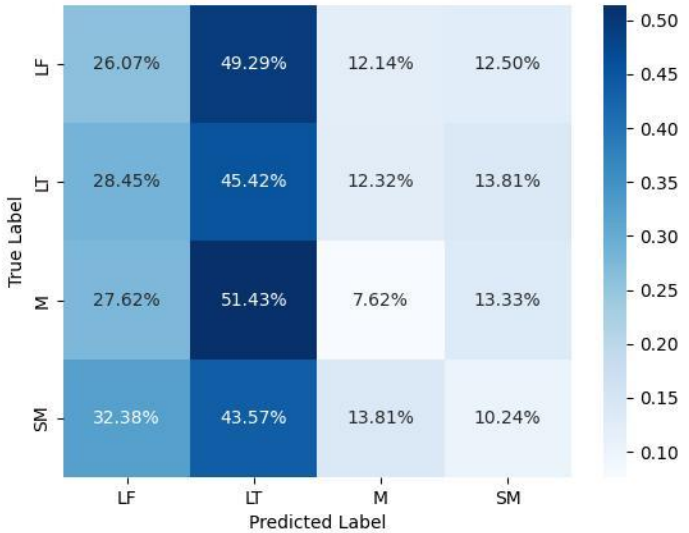
Results: Four Classes

Accuracy = 31.45 %



Zero

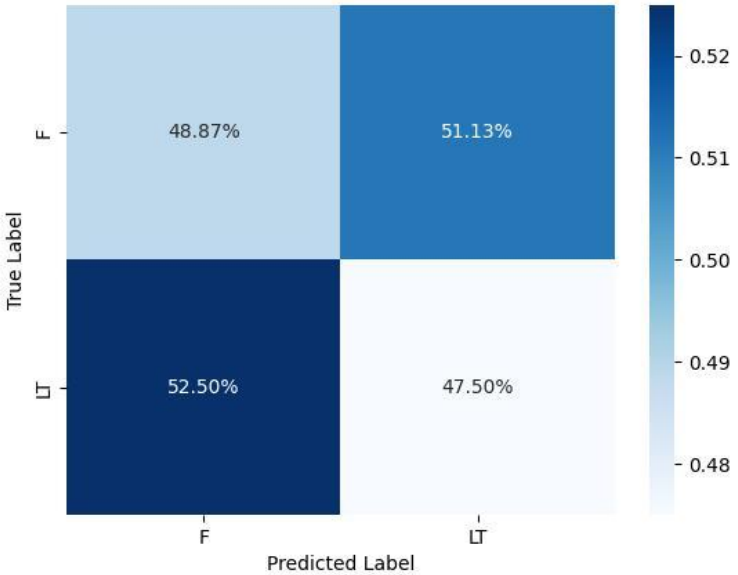
Accuracy = 31.45 %



Drop

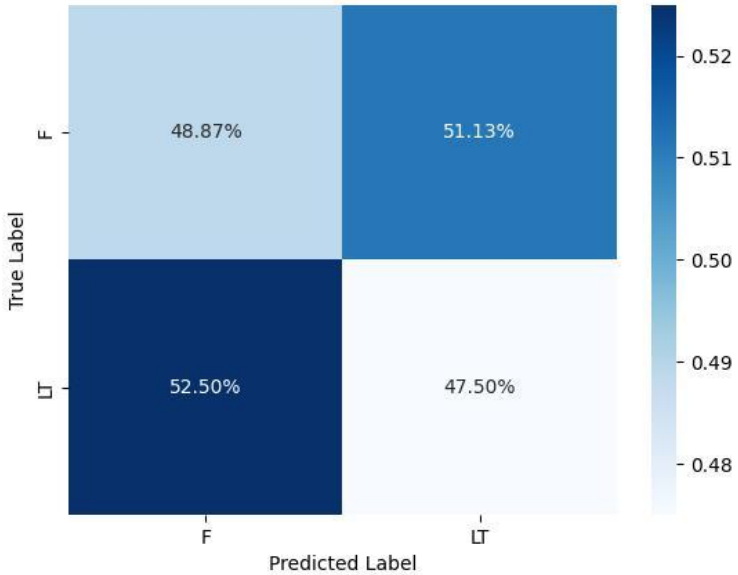
Results: Two Classes

Accuracy = 48.18 %



Zero

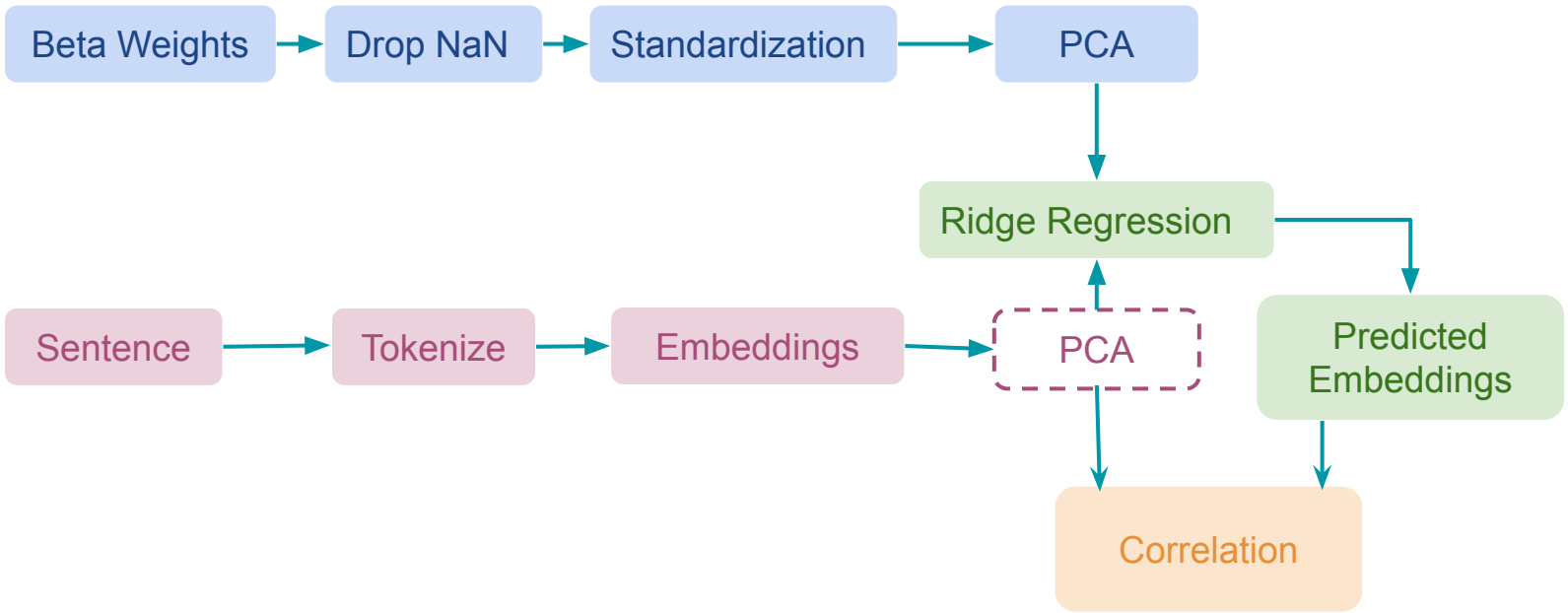
Accuracy = 48.18 %



Drop

Decoding

Decoding


Beta Weights
Drop NaN
Standardization
PCA
Ridge Regression
Sentence
Tokenize
Embeddings
PCA
Predicted Embeddings
Correlation

Setup

- Dropping NaN values.
- Standardization using StandardScaler.
- Classifier: Ridge Regression.
- Nested 5-fold cross validation.
- Hyper-parameter tuning using grid search.
- Calculate the correlation between predicted and actual embedding.
- Permutation test to check if the results are statistically above chance.
    - shuffle of the neuroimaging data and sentence embeddings for the stimuli 100 times to create a null distribution

Sentences

- Tokenization: `['[CLS]', 'some', 'birds', 'are', 'robin', '##s', '[SEP]']`
- Sentence Embedding Using Bert

- PCA:
    - PCA to keep 20 most important features of sentence embeddings
    - Keep all 768 features

Decoding: Entire Sentence

	Average Corr.	Average MSE	Average p-value
Entire Embeddings	0.0157	0.031	0.22
PCA over Embeddings	-0.003	0.79	0.52

The repetition of 'Some' and 'are' in all sentences makes them very similar. This similarity may make it challenging to decode them.

What if we remove these two keywords from the sentences and then classify them?

Decoding: Two Words

	Average Corr.	Average MSE	Average p-value
Entire Embeddings	0.021	0.039	0.14
PCA over Embeddings	0.030	0.97	0.21

Do the sentences contain enough information about their class to be correctly classified?

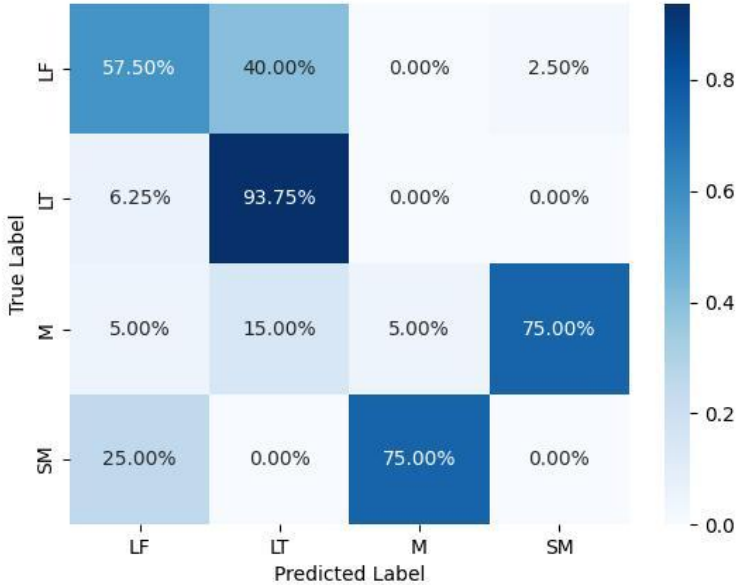
Sentence Embeddings Classification

Setup

- Classifier: Logistic Regression.
- Nested 5-fold cross validation.

All Sentence Embeddings (Unbalanced)

- Accuracy: 61.87%

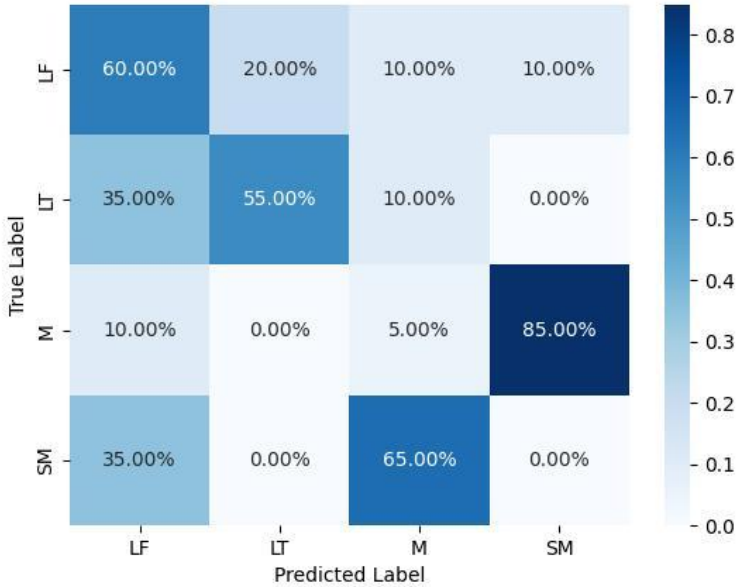


Which classes are most likely to not be correctly classified?

All Sentence Embeddings (Balanced)

- Accuracy: 30%

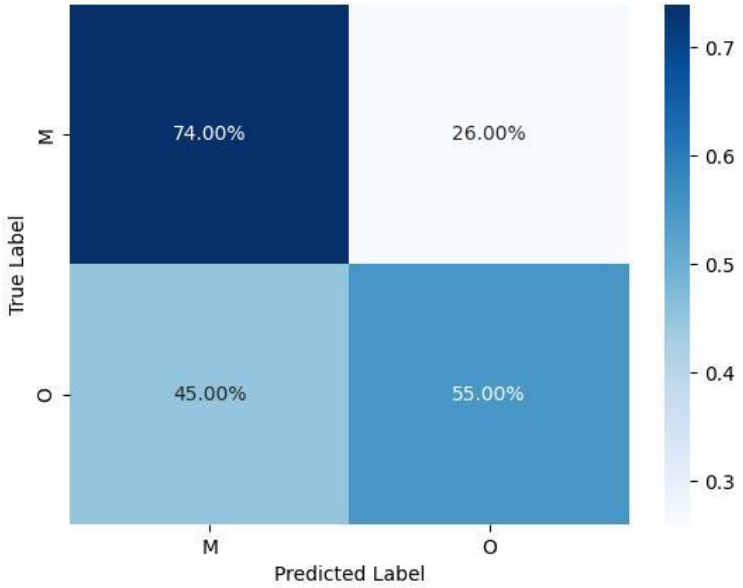
- Most of the time:
  - Predicts M as SM
  - Predicts SM as M
  - Predicts LF as LF
  - Predicts LT as LT



M vs. SM, LT, and LF Grouped as O (Balanced)

- Accuracy: 62.5%

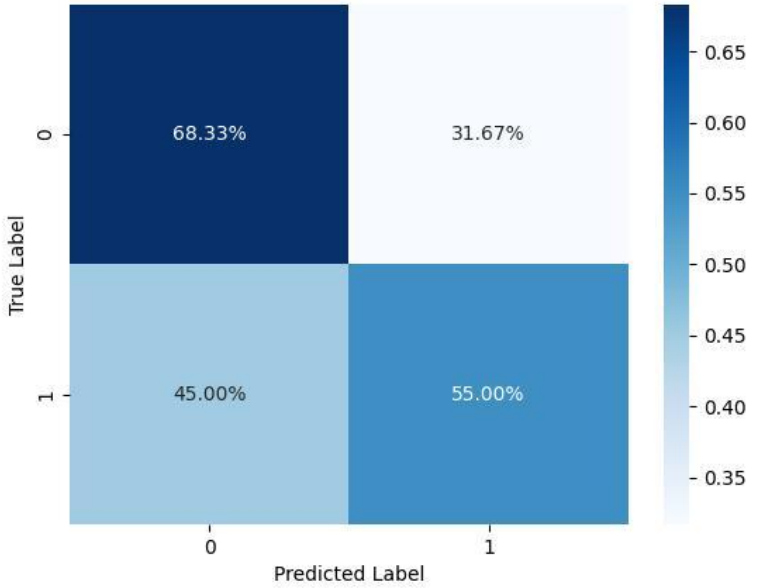
- Wrong Predictions:
  - LT: 0 out of 12
  - LF: 2 out of 5
  - M: 5 out of 20
  - SM: 3 out of 3



M vs. SM and LF Grouped as F (Balanced)

- Accuracy: 57.5%
  *M: 0

- Wrong Predictions:
  - LF: 4 out of 12
  - M: 8 out of 20
  - SM: 7 out of 8



It seems like the problem is with SM and M.

How M and SM can be classified?

Similarity Between M vs. SM

- Some_desks_are_diamonds (SM)
  Some_desks_are_junkyards (M)

- Some_hearts_are_diseases (SM)
  Some_hearts_are_dwellings (M)
  Some_hearts_are_ice (M)
  Some_hearts_are_zoos (SM)

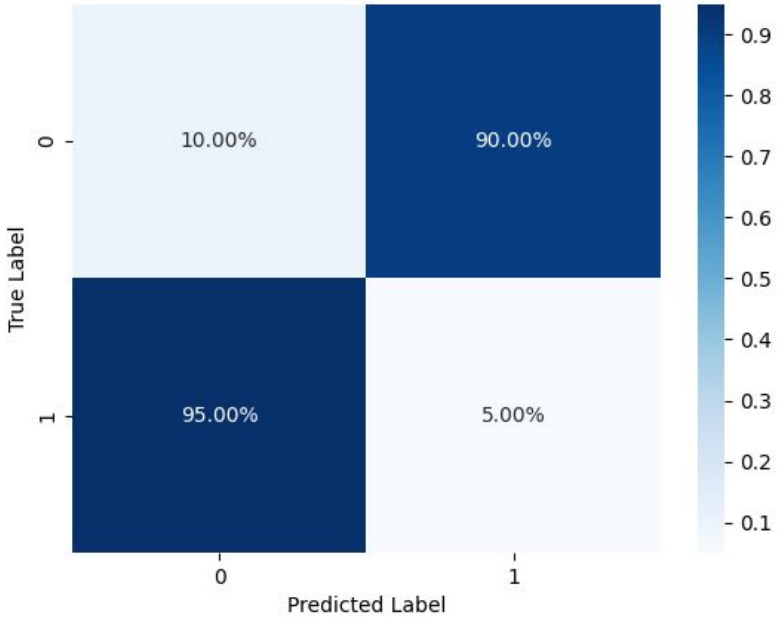
Group sentences containing three identical words. These sentences can not be separated into training and test sets; they are included in either the train or test set.

Cross Validation

- Groups with two sentences: 14
- Groups with four sentences: 3
- In cross validation, the test set has:
  - 4 groups with 2 sentences
  - 2 groups with 4 sentences
  - 2 groups with 2 sentences, 1 group with 4 sentences

M vs. SM (Balanced)

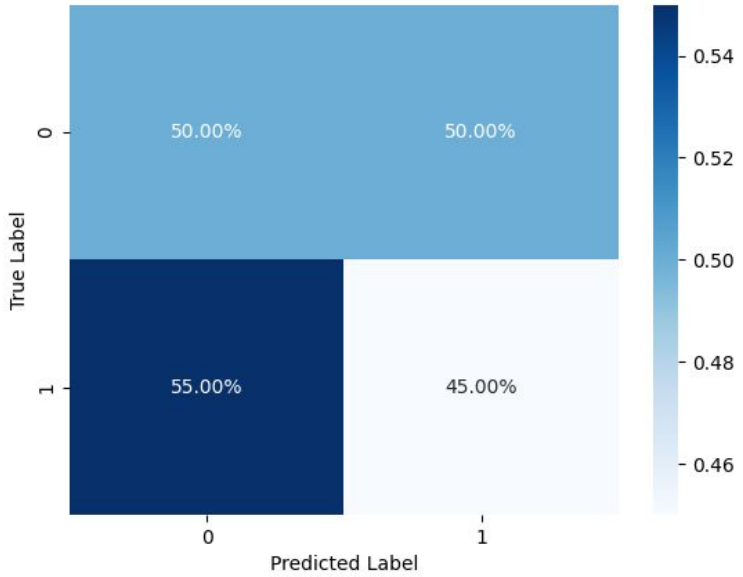
- Accuracy: 7.5%
  *M: 0



What are the classification results for random data?

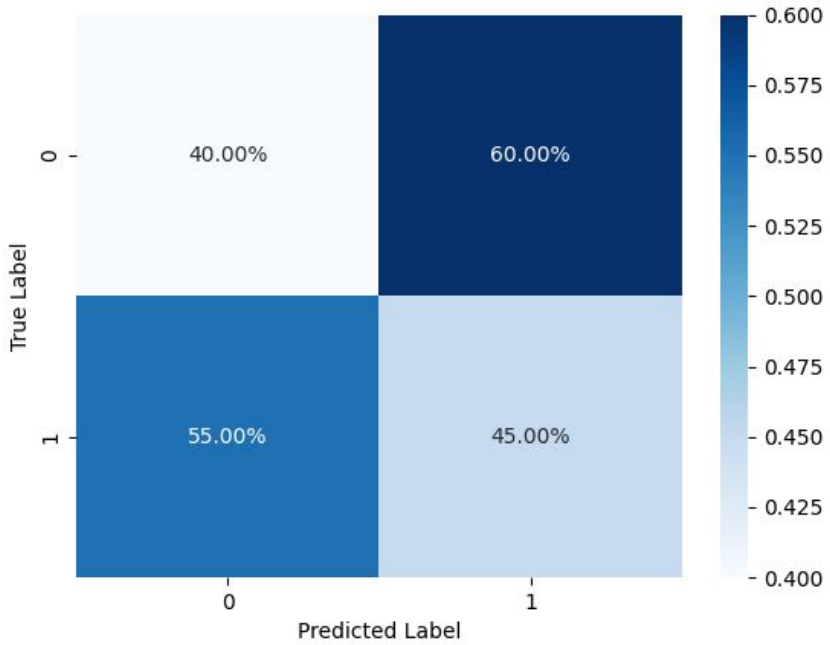
Random Labels

- Accuracy: 47.5%
  *M: 0



Random Embeddings

- Accuracy: 42.5%
  *M: 0



References

Vogindroukas, Ioannis et al. “Language and Speech Characteristics in Autism.” Neuropsychiatric disease and treatment vol. 18 2367-2377. 14 Oct. 2022, doi:10.2147/NDT.S331987