Predicting Executive Function Scores Using Linear Regression

Rohini Lahiri
Springboard Data Science Career Track
June 2019

The Problem

- Executive function (EF) is a broad term for the cluster of cognitive processes that take place in the prefrontal cortex of the brain.
- Proper EF is responsible for self-regulation in humans, as well as the ability to plan, organize, and maintain focus on short-term tasks.
- Executive dysfunction can severely impact an one's ability to learn or self-regulate, making it difficult to meet the demands of a workforce successfully or struggle with debilitating mental health issues.

Motivation

- Build a linear regression model which can accurately predict one's executive function scores by ...
  - Finding major lifestyle trends related to EF
  - Identifying potential factors related to low EF
- Determine if successful executive function ability is influenced by BMI

Data Collection & Preparation

- The dataset is available in the Public Library of Science repository as an Excel file with 513 subjects from two separate high schools in Selangor, Malaysia. Any adolescents suffering from neurological or psychiatric disorders, medical conditions, learning disabilities, history of traumatic brain injuries, or who had difficulties in performing physical activities were excluded from the study.
- Participants provided answers to prompts regarding age, date of birth, sex, ethnicity, meal consumption patterns, physical activity, and sleep quality through self-administered questionnaires.
- Participants' parents provided answers to demographic information regarding household size, income category, father's years of education, and mother's years of education.
- Height and weight measurements were taken twice for each subject on-site at the time of experiment, with the mean value of each measurement used as the final measurement.

Measuring Executive Function Ability

Executive function is broken into three scores:

I. **Interference:** the ability to resist distraction and maintain focus

II. **Working Memory:** the ability to maintain and manipulate information over a short period of time

III. **Cognitive Flexibility:** the ability to shift attention in response to changing task demands

Measuring EF Ability, Contd.

- Three separate tests were conducted to measure executive function:

I. **Interference:** Stroop Color and Word Test

II. **Working Memory:** Digit Span Test

III. **Cognitive Flexibility:** Trail-Making Test

The Stroop Color and Word Test

A cognitive test based on the belief that individuals can recognize words faster than they can identify and name colors.

Subjects are presented with a list of color words and must successfully name the ink color of the word presented, instead of the actual word, within a given amount of time.

A higher score denotes better capacity for inhibition responses, i.e. the ability to resist distraction and maintain focus.

The Digit Span Test

A test which measures short-term memory, in which participants are given a sequence of numbers to memorize and repeat back.

The sequence of numbers increases by one with each successive trial.

Task performance is gauged by the average number of digits recounted correctly. A higher score denotes better working memory.

1. 5 9 0
2. 4 8 6 1
3. 7 3 0 9 4
4. 2 4 9 6 5 8
5. 1 4 6 8 2 4 5
6. 3 9 2 1 5 7 6 0
7. 6 2 5 7 3 9 1 8 4
8. 0 6 3 8 9 4 1 7 2 5

Trail-Making Test

Part A

Part B

A test in which participants are given two pieces of paper - one with numbered circles, randomly arranged, and the other containing numbers and alphabets, also randomly arranged.

Subjects must first draw lines between the circles in an ascending order, and then switch to drawing lines connecting the numbers and alphabets in sequential order.

The time taken to complete both tasks is recorded, and the task-switching score is calculated by subtracting the time taken to complete the first part from the second part.

In this case, a lower score denotes better performance.

Methodology

I. Statistical Inference
II. Basic Linear Regression (with train-test splits) and 5-Fold Cross Validation
III. GridSearching
IV. LASSO Regression
V. Ordinary Least Squares (without train-test splits)
VI. Hierarchical Regression

Statistical Inference

Visual EDA and statistical inference dictated that the following features were most influential when predicting each EF score:

Interference: Household size, income category, BMI-for-age, and sleep percent

Working Memory: Global sleep category, household size, income category, BMI-for-age, and sleep percent

Cognitive Flexibility: Sex, household size, and age

A standard correlation matrix was graphed in an effort to find noticeable correlations and check for collinearity.

Linear Regression (with train-test splits) and Cross-Validation

Basic linear regression was conducted three separate times – once for each of the three target variables. Each train-test split included all predictor variables, trained against one executive function score. Predictions were made on the test data and the outcomes were as follows:

Interference R^2 = -0.029

5-Fold CV Score = -0.04

Working Memory R^2 = 0.11

5-Fold CV Score = 0.011

Cognitive Flexibility R^2 = -0.023

5-Fold CV Score = -0.13

GridSearching

Based on the negative $R^2$and cross-validation scores, it became clear that feature selection was necessary.

GridSearching was performed in an effort to determine the ideal parameters for three types of regularized regression – LASSO, Ridge, and Random Forest Regression.

The following parameters were found:

- **LASSO (α)** = 0.1
- **Ridge (α)** = 1000
- **Random Forest (max_depth)** = 2

LASSO Regression

LASSO is a very useful linear regression model focusing on shrinkage estimation in an effort to minimize collinearity. It performs L1 regularization, adding penalties to the absolute value of the magnitude of coefficients. As such, insignificant coefficients are eliminated from the model entirely.

LASSO regression for each target variable followed next, with $\alpha = 0.1$ and the same train-test splits used for basic linear regression.

The following LASSO scores were generated:

- **Interference** = -0.0102
- **Working Memory** = 0.111
- **Cognitive Flexibility** = -0.425

LASSO Regression, Contd.

The following LASSO graphs were generated:

LASSO for Interference

LASSO for Working Memory

LASSO for Cognitive Flexibility

LASSO Regression, Contd.

- Basic linear regression followed again for each of the three EF scores. Each train-test split was made of the most salient features defining each score.

➢ **Interference:** PFS_CAT and Income_CAT

R^2 = 0.018; 5-Fold CV Score = 0.003

➢ **Working Memory:** Global_Sleep_CAT and Income_CAT

R^2 = 0.094; 5-Fold CV Score = 0.043

➢ **Cognitive Flexibility:** Actual_age_C, Sex, PFS_CAT, Household_size, and Income_CAT

R^2 = 0.053; 5-Fold CV Score = -0.039

The basic linear regression analyses for all three targets improved.
The 5-Fold CV for CF performed worse however.

Ordinary Least Squares (without train-test splits)

Linear regression allows for model fitting using OLS. OLS is a linear least squares method for estimating the coefficients of a linear model by minimizing the squared residuals.

The outputs of this algorithm include R^2 and an adjusted R^2, the latter of which has been used in this analysis. The adjusted R^2 takes the number of variables in the model into account in an effort to minimize any artificial inflation of the R^2 value due to increased dimensionality.

Interference R^2 = 0.025

Adjusted R^2 = 0.014

Working Memory R^2 = 0.087

Adjusted R^2 = 0.074

Cognitive Flexibility R^2 = 0.047

Adjusted R^2 =0.036

Hierarchical Regression

Finally, hierarchical linear regression was performed, three separate times.

The protocol followed the one detailed in the journal article so that the R^2 values could be compared fairly.

The model was split into three distinct phases:
Phase I: Age, sex, monthly household income, parents' years of education, and household size
Phase II: BMI-for-age
Phase III: Meal intakes, sleep quality, physical activity and aerobic fitness
Level of Significance: $p < 0.05$

Then, linear regression models were run without train-test splits. The following comparisons were made:

Overall Interference R^2 = 0.033 (journal); 0.023 (hierarchical)
Overall WM R^2= 0.128 (journal); 0.081 (hierarchical)
Overall CF R^2 = 0.061 (journal); 0.035 (hierarchical)

Conclusion

- This dataset is unsuitable for building functional or accurate predictive models.
- Statistically, BMI proved to factor strongly in predicting executive function abilities.
- Regardless of statistical significance however, the R^2 values obtained through each run of linear regression were very low.
  - The viability of each model improved significantly as the most important features for each of the three executive EF scores were selected using LASSO. The subsequent regression runs provided similar or slightly improved R^2 values.
  - With hierarchical regression, the R^2 values calculated were consistently lower than the ones published in the journal article. Nevertheless, the R^2 values themselves were very low.
- The results are statistically significant, but do not bear practical significance.

Client Recommendations

- Schools can design programs that support students from lower socioeconomic backgrounds by providing free or reduced meal options at school. Stricter guidelines for physical education classes can also be put into action.
- If a patient only shows certain risk factors, counselors can recommend Cognitive Behavioral Therapy (CBT) to help patients develop better self-regulation skills.
- At home, parents and the students themselves can use the data to implement better daily and sleep routines.

References

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