Exploring the Relationship between Language Ability and Executive Functioning

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Background

Executive Functioning:

- A set of higher-order cognitive processes responsible for regulating and coordinating mental activities essential for goal oriented behavior and adaptive problem-solving
- A uniquely human cognitive ability, a key component of which is exhibition of inhibitory control (Shin et al, 2015)

"The Bilingual Advantage":

- The idea that bilinguals may have cognitive benefits including improved executive functioning
- The validity of this theory is inconclusive due to various contradicting trends
  - Supported by the Adaptive Control Framework theory proposed by Green and Abutalebi in 2013
  - However, performance on tasks that measure executive functioning vary between bilinguals due to factors such as: code switching frequency, phonological and orthographic similarity of L2 to English, L2 proficiency (inter vs between language interference), cortical thickness (Sumiya & Healy, n.d., p.), (Kroll & Chiarello, 2015).

The Stroop Task:

- In "Studies of Interference in Serial Verbal Reactions" by Stroop in 1935 established that an automatic process, such as reading, can interfere with one's ability to accurately complete an alternative goal
  - The "Interference Effect", now more widely known as the "Stroop Effect" occurs when there is conflict between the word's meaning and the color that it is presented in, causing the participant to take longer interpreting the color due to interference they may experience
  - This phenomenon demonstrates the challenges in inhibiting automatic processes and highlights complexities of cognitive control for both monolinguals and multilinguals.
- The design enabled us to measure participant's ability to inhibit an automatic response (reading) and maintain cognitive flexibility when confronted with conflicting stimuli

My hypothesis for this project is that bilingual or multilingual individuals will show a smaller Stroop Effect, higher accuracy, and faster reaction time relative to their monolingual counterparts, which would theoretically correspond with enhanced executive functioning abilities. The underlying hypothesis is that experience with code (language) switching strengthens the existing neural circuitry that also works to facilitate executive functioning.

Subjects

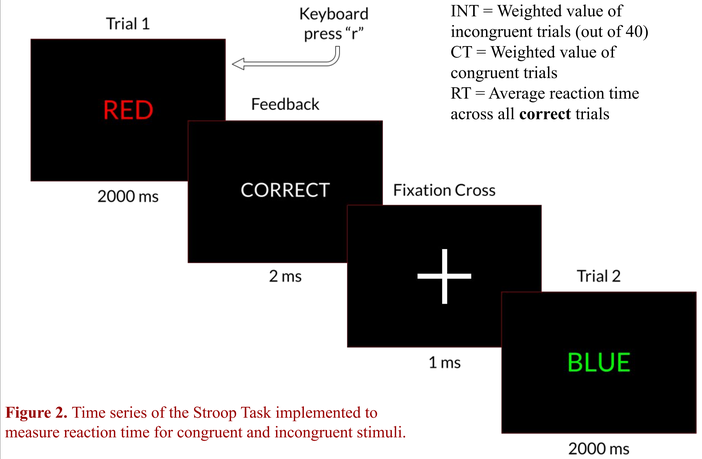
	Monolingual Subjects	Multilingual Subjects	Statistics
Sample Size	10	11	
Gender Distribution (M:F)	1:4	2:9	$\chi^2(2) = 0.01$ $p > 0.05$
Age Mean (S.D.), Range	22.5 (5.8), 15-30	19.2 (3.1), 14-25	$(F(2,21) = 3.6$, $p > 0.05)$

Table 1. Subject demographic data and summary statistics.

- Subjects were not informed of the hypothesis of the study
- Subjects were recruited from the UPC BUGS JR cohort, as well as other USC communities
- Survey was administered to verify and assess language ability and collect demographic data
- Subjects were verified for the following criteria for eligible participation
  - Adequate motor control, comfortable using a computer keyboard
  - No known neurological disorder
  - Fluent in English
  - No known vision impairments (excludes corrected vision)

Figure 1. Two sample stimuli, for the congruent (left) and incongruent (right) behavioral task . Subjects were instructed to give a key press indicating the ink color of the word.

Methods



INT = Weighted value of incongruent trials (out of 40)
CT = Weighted value of congruent trials
RT = Average reaction time across all **correct** trials

Figure 2. Time series of the Stroop Task implemented to measure reaction time for congruent and incongruent stimuli.

- 1 ms interstimulus interval (ISI)
- 2000 ms stimulus interval (if not answered quicker)
- Feedback between trials
- All subjects participated in the Stroop Task from the same computer
  - Controls for keyboard and display differences
- The Stroop Task was administered on PsyToolKit (software for running cognitive-psychology experiments)
- The Stroop Effect or the "Interference Effect" was calculated using the equation: (INT×RT)-(CT×RT) = Stroop

Data:

- Appropriate demographic data was assigned numeric value (e.g. monolinguals = group 1, bi/ multilinguals = group 2)
- Collected data was analysed using R Studio
  - Linear regression models
  - Spearman's correlation, due to abnormal data distribution

Results

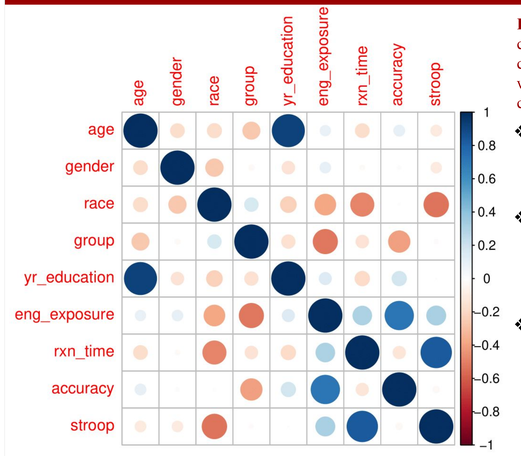


Figure 3. A correlation matrix showing the relationship between all covariates. The color bar on the right signifies Spearman's rho (the correlation coefficient). Cool tones represent a positive correlation, the warm tones a positive correlation. The deeper the color, the stronger the correlation.

- The matrix shows a positive correlation between accuracy and English exposure. The Stroop Task was administered in English, and the data suggests that those with more exposure to English performed better.
- Small positive correlation between Stroop Effect and English exposure.
  - Higher English exposure was more common amongst the monolingual subject group, potentially implying an inferior performance (larger Stroop Effect) is related to language.
- Group had a small negative correlation with accuracy, potentially implying more cognitive interference which led to reduced accuracy.
  - This could be between or interlanguage interference, depending on variables such as language proficiency and code switching frequency.

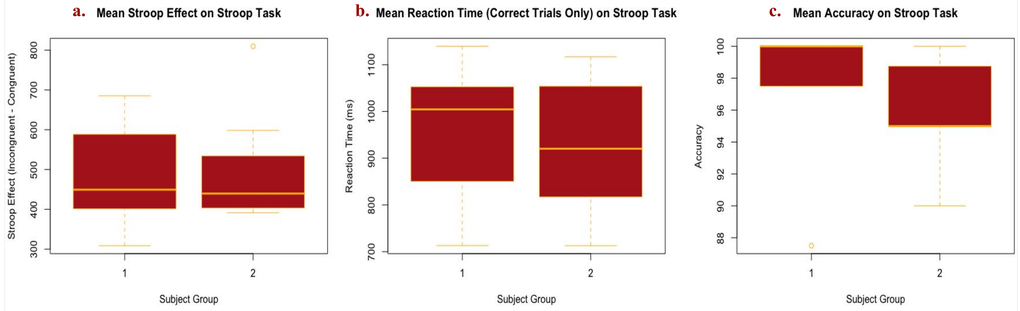


Figure 4: Box plots comparing subject group 1 (monolinguals) and subject group 2 (multilinguals) on three performance metrics evaluated during the Stroop Task.
Figure 4a. When comparing the Stroop Effect, both groups performed similarly with the monolingual group slightly underperperforming.
Figure 4b. When comparing reaction time, the monolingual subject group showed a higher mean, however there was significant overlap in performance.
Figure 4c. The bilingual subject group showed a lower mean accuracy, which disagrees with the original hypothesis.
None of these results were statistically significant using evaluation of $p<0.05$.

Conclusions, Implications, and Future Directions

Conclusions:

- Due to small sample size and other limiting factors, there were no statistically significant correlations using the benchmark of $p<0.05$
- English exposure showed a small positive correlation with both accuracy and Stroop Effect
  - The Stroop Task was administered in English, and that is a component unable to be isolated from accuracy. However, in the future if the test was administered in the participants' L2, perhaps we could yield different results.
- A larger Stroop Effect from monolingual (less linguistically exposed) individuals could imply more difficulty inhibiting automatic processing due to less cognitive flexibility.
  - Generally, multilingual subjects reported less frequent average exposure to English.
    - The Adaptive Control Framework (Green and Abutalebi, 2013) assumes which cognitive mechanisms are engaged is dependant on environmental demands. These factors may affect the neural network in response to language experience (Kroll & Chiarello, 2015).
- Negative correlation between group and accuracy could potentially imply more cognitive interference from subject's L2.
  - The monolingual subject group had an older mean age, and therefore have experienced more education, which potentially influenced accuracy.
  - Bilingual people are known to experience more between language interference when their proficiency is lower, whereas highly proficient bilinguals experience more interlanguage interference (Shin et al, 2015).
  - The phonological and orthographic similarity between the color names in subjects' L1 and L2 could also influence accuracy, reaction time, and Stroop Effect.
    - Orthographic similarities between languages eg. "red" in English and "rot" in German could cause decrease in accuracy
    - Although the Stroop Task is a written task, studies have implicated involvement of unintentional phonological processing, which could potentially influence how the stimuli was interpreted, creating between interference. Eg. "blue" in English and "ブルー" (Buryū) in Japanese have no orthographic overlap, but the phonology could unintentionally be interpreted during lexical access (Sumiya & Healy, n.d., p.).
- The monolingual subject group showed a slower mean reaction time compared to the bilingual group. This aligns with my original hypothesis that bilingual individuals more adeptly blocked cross stimuli interference, therefore performing better on the Stroop Task. This was potentially reflected in the data but since error bars completely overlap, a large sample size is required.

Future directions:

- This study should be reconducted in the future, with an increased sample size and compensation for participants
  - Undergraduate researchers are USC have plans to expand on my original research in the Fall of 2023 under the guidance of Dr. Barakat
- With more time, I would examine this through a phonology lens, examining how languages 'more similar' to English overlap with the Stroop Task stimuli.
  - This would provide information for understanding the effect of anticipatory processing on a multilingual environment.
  - This could potentially include implementing a bilingual Stroop Task in order to further subdivide the multilingual subject group.

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