The Effect of Bilingualism on Perceptual Processing in Adults

by

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ABSTRACT

The experience of language can, as any other experience, change the way that the human brain is organized and connected. Fluency in more than one language should, in turn, change the brain in the same way. Recent research has focused on the differences in processing between bilinguals and monolinguals, and has even ventured into using different neuroimaging techniques to study why these differences exist. What previous research has failed to identify is the mechanism that is responsible for the difference in processing. In an attempt to gather information about these effects, this study explores the possibility that bilingual individuals utilize lower signal strength (and by comparison less biological energy) to complete the same tasks that monolingual individuals do. Using an electroencephalograph (EEG), signal strength is retrieved during two perceptual tasks, the Landolt C and the critical flicker fusion threshold, as well as one executive task (the Stroop task). Most likely due to small sample size, bilingual participants did not perform better than monolingual participants on any of the tasks they were given, but they did show a lower EEG signal strength during the Landolt C task than monolingual participants. Monolingual participants showed a lower EEG signal strength during the Stroop task, which stands to support the idea that a linguistic processing task adds complexity to the bilingual brain. Likewise, analysis revealed a significantly lower signal strength during the critical flicker fusion task for monolingual participants than for bilingual participants. Monolingual participants also had a significantly different variability during the critical flicker fusion threshold task, suggesting that becoming bilingual creates an entirely separate population of individuals. Future research should perform analysis with the addition of a prefrontal cortex electrode to determine if less

collaboration during processing is present for bilinguals, and if signal complexity in the prefrontal cortex is lower than other electrodes.

ACKNOWLEDGMENTS

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INTRODUCTION

It comes as no surprise that being bilingual has shown to have many advantages in the social world such as being able to communicate with a wider proportion of the world (Showstack, 2010). However, instead of being regarded as more competent than monolinguals, bilinguals in the United States (particularly those whose first language is not English) are often regarded as less capable than native English speakers and discriminated against in medical, political, and even social environments (Cummins, 2000; Achugar, 2009). Bilinguals with a non-English first language have the experience of being looked down on for their accents or the increased difficulty naming objects in the environment (Marion, 2012).

Contrasting with this stigma, research on bilingualism has shown that bilinguals have shown marked differences in their cognitive, attentional and perceptual abilities, and even in their connectivity and functional organization in the brain (Bialystok, 2007; Duran & Enright, 1983; Marian & Shook, 2012; Martin-Rhee & Bialystok, 2008). Early research focused primarily on cognitive and attentional tasks and sought to understand why bilingual individuals seemed to perform better on tasks that involved learning rules, switching attention, and memory (Duran & Enright, 1983; Nanez & Padilla, 1993; Nanez & Padilla, 1995). In one of these studies, Agnes & Mehler (2009) studied 7-month-old babies that either had or had not been living in a bilingual household and their ability to learn a rule to obtain a reward using eye-tracking software. In order to learn the rule, babies had to avoid an attractive stimulus on the opposite end of a screen from a target. Researchers measured the time it took the babies to focus from the attractive stimulus to the target stimulus over a period of trials, and found that pre-dating the onset of speech, babies raised in a bilingual household were able to learn the rule more quickly than babies that were raised in a monolingual household. This suggests that the cognitive advantage for bilinguals begins before the acquisition of language (Agnes & Mehler, 2009). In a series of studies done by Bialystok (Bialystok, 1999; Bialystok et al., 2004; Bialystok et al., 2005; Bialystok, 2006; Bialystok, 2007), the researchers report data that suggests that bilinguals have an advantage in tasks that require switching tasks (flanker task) and focusing attention. They suggest that due to the constant suppression and activation of both language modalities, bilinguals develop more acute attentional control and better ability to suppress information to focus on other information (Bialystok et al., 2006).

Other research studying these executive functions (working memory, inhibition of irrelevant stimuli, etc.) has been mixed, leading to a slight controversy when studying a bilingual advantage (Solveri et al., 2011). While some studies list that a bilingual advantage does not exist with tasks that involve the central executive (Namazi & Thordardottir, 2010), others doubt that the executive measures are accurately captured in the data. One review of bilingual literature describes the mixed nature of executive control research as the result of individual differences and variance between participants, the linguistic component of applied tasks, or the use of measures that do not allow for a wide range of responses (Bialystok, 2017). If an assessment seeking to measure performance of the central executive has a linguistic component to it (such as the Stroop task), a bilingual participant may have the additional task of suppressing one language modality to process using the other language necessary for the task, which would add more complexity and a greater cognitive load to the task relative to what a monolingual participant might experience, regardless of any advantages that might exist in pro-bilingualism advantage literature (Grundy et al., 2017).

Perceptual Processing in Bilingualism

One field of research within bilingualism that has shown more consistent support for a bilingual advantage is studying the perceptual abilities of bilingual individuals. Athanasopoulos and colleagues (2011) measured the frequency in which Japanese-English bilingual participants spoke each language in everyday life. Then, participants were given a task with color pairs and asked to tell if the pairs were the same or different. Participants that spoke Japanese more frequently than English were more sensitive to the color pairs in this task. Researchers suggest that it might be the fact that Japanese has more words for the different variations for colors (For example, there are more words for shades of blue in Japanese than in the English language). This finding implies that due to the enhanced vocabulary relating to the stimulus set, participants are more likely to report an enhanced ability to differentiate between the colors presented to them, suggesting that the language itself can provide for increased perceptual skills. If this is true, it opens up a discussion regarding whether language created this sensitivity to stimuli over time, as if increased use with age of the secondary language leads to more perceptual sensitivity, or if simply the presence of the language is enough to increase perception.

Wimmer and Marx (2014) conducted an experiment on grade school age children that studied whether more refined perceptual abilities were present even in the early years of knowing a second language. In their experiment, a series of ambiguous figures (pictures that could be identified depending on the interpretation as two different things, such as a rabbit and a duck) were presented to monolingual and bilingual children. The children first identified the first figure they saw, and then were told there was a second interpretation of the figure. Significantly more bilingual children were then able to report the identity of the second image in the figure than the monolingual children. These results suggest that bilingual children may have superior visual perception relative to monolingual children (Wimmer & Marx, 2004).

Supporting the claim that the bilingual population may have better performance in perceptual processing tasks is a recent study done by Holloway and Nàñez (2017) which tested the perceptual skills of bilingual and monolingual individuals. The researchers used two psychophysical tasks that measured the visual capabilities of the eye and word decoding skills and compared between the two groups. The critical flicker fusion threshold (CFFT) and the Landolt C tasks are both non-linguistic and found to be highly correlated with both word and non-word decoding (Holloway et al., 2014). CFFT is additionally highly correlated with cognitive ability (Mewborn et al., 2015). In this study, bilinguals showed better performance on both tasks, showing a higher word-decoding capability in bilingual participants relative to monolingual participants, suggesting enhances perceptual processing capabilities in the bilingual population.

Neuroimaging and Bilingualism

More recently, there has been a shift in the bilingual research to consider the neurological component to why these effects may exist. One of the earliest studies in bilingualism research to look at the brain is Kim et al. (1997), which utilized functional magnetic resonance imaging (fMRI) to determine the physical location of the mechanisms underlying language. The researchers use two groups of bilinguals: one that had learned their second language before the age of twelve (early bilinguals), and one that learned their second language after the age of twelve (late bilinguals). For early bilinguals, the second language showed activation in the same or a close location to the activation of the native (first) language. For late bilinguals, the activation of the second language had significant physical separation from that of the native language, suggesting that the organization of the brain is significantly affected by the stage of development an individual learns and has exposure to their second language. This implication is emphasized in later research through the use of fluorescein angiography, voxel-based morphology, diffusion-tensor imaging and magnetoencephalography (MEG), all of which show evidence for increased grey matter, white matter integrity, and hemisphere connectivity in the brains of bilingual individuals relative to the brains of monolingual individuals (Bialystok et al., 2005; Mechelli, 2004; Luk et al., 2011; Olsen et al., 2015; Hilchey & Klein, 2005; Połczyńska et al., 2017). The functional changes in the brain through the use of these techniques are widely studied to understand the cortical differences between bilingual individuals and their monolingual counterparts. As with any other science, the next step of understanding these differences is to look at it in a more microscopic view.

Electroencephalograph

Research in bilingualism using the electroencephalograph (EEG) is limited and of growing interest to research today due to its non-invasive and portable capabilities (Abutalebi et al., 2013). More enlightening is the capability of the EEG to show unmatched temporal resolution in populations of neurons. Grundy et al. (2017) conducted a study in which bilingual and monolingual participants were evaluated during a flanker task using the EEG and found higher complexity (calculated using sample entropy and multi-scale entropy by analyzing the number of times two consecutive data points occur during a pre-specified amplitude range and taking) for bilingual individuals in the occipital region during the task, as well as more localization in the occipital lobe relative to monolingual participants. The task involved switching between the color of shapes, parity of numbers, and the case of letters which were sometimes combined to create a conflict in attending to the target stimuli (i.e., they were to say if the letter was uppercase or lowercase, but the color of the letters were changing through the task in addition to the case of the letter). EEG data for monolingual participants showed more complexity in the frontal lobe and collaboration between the occipital and frontal lobes. This suggests that there is less need for top-down processing for bilingual participants (Grundy, Anderson & Bialystok, 2017) than monolingual participants due to reduced frontal lobe activity in bilingual participants during these tasks.

Another theory for this reduced frontal lobe activity comes from research using EEG to understand the link between performance on executive switching tasks on individuals with high and average IQ scores. Thatcher et al. (2016) found that participants with a higher IQ also had more localization and less collaboration between cortical areas during executive tasks, and suggested that participants with a higher IQ had more efficient local information processing mechanisms in place. While there is no evidence to suggest that bilingual individuals have a higher IQ than monolingual individuals, the idea parallels that more localization and less collaboration in the brain could stem from higher efficiency in information processing.

While there is a large base of research using EEG to detect differences in everything from meditation to brain lesions (Cahn & Polich, 2006; Połczyńska et al., 2017), there is a distinct lack of research using the EEG to understand the perceptual performance effects seen in bilingualism literature. EEG research has focused on tasks involving the central executive, which has shown mixed results in research (Solveri et al., 2011), and failed to transition into understanding a more consistent effect in bilingualism research.

THE PRESENT STUDY

Research Questions

Based on the previously discussed literature, bilingual individuals have shown to have better performance on perceptual tasks. What previous literature has not shown, however, is why this effect exists. If literature that involves neuroimaging is examined, studies outside of bilingualism literature have found that there is more local processing done and a lower signal strength (or information flow) in individuals that have a higher IQ during executive tasks. Adopting this same mindset, the present study seeks to understand if the performance on perceptual tasks could be due to lower signal strength. By collecting data using the EEG and analyzing the signal strength, the average amount of information flow used to complete a task can be determined. Do bilinguals need a lower information flow to complete the same perceptual tasks as monolinguals? And if so, can this explain why bilinguals would have better performance on these same tasks? If bilinguals require a lower signal strength to complete perceptual tasks and still do the same or better on them than monolinguals, does this mean that they have more efficient information processing, paralleling the findings of intelligence studies that show lower information flow in perceptual tasks for those with a higher IQ (Thatcher, 2016)? If the amount of energy needed to complete the perceptual tasks is less for bilinguals relative to monolinguals, this will add evidence to the claim that the brain changes with experience, and that language is qualifies as one of those experiences (Mechelli et al., 2004; Bialystok et al., 2007; Grundy et al., 2017; Abutalebi et al., 2013; Hichey & Klein, 2005; Olsen et al., 2015; He et al., 2009; Duong et al., 2005; Waldie et al., 2009; Gold et al., 2013).

Hypotheses

The present study seeks to investigate the answer to these questions by analyzing bilingual and monolingual participants during two perceptual tasks, and one task that involves the central executive (always done between the two tasks to prevent crossover between the two perceptual tasks). We focus here on bilingual participants that scored a 4 or above on the Language Assessment Scales in both the English and Spanish language, and monolingual participants that scored a 2 or below on the Spanish language scale, and a 4 or above on the English language scale. The following hypotheses are proposed to analyze the effects of bilingualism on perceptual processing.

H1: Bilingual participants will have a higher Critical Flicker Fusion Threshold than monolingual participants, remaining consistent with previous literature. This was tested in 2017 by Holloway et al., and showed a higher score for bilingual than monolingual participants, suggesting that bilingual participants have a better non-linguistic word decoding. Replicating this finding would be consistent with the findings of previous research.

H2: Bilingual participants will show better performance on the Landolt C task relative to monolingual participants, remaining consistent with previous literature. This was also tested in 2017 by Holloway et al. showing that bilingual participants had better performance on this task relative to monolingual participants. The present study seeks to replicate this finding to show better performance on perceptual tasks as is consistent with the literature.

H3: There will be no statistical differences between bilingual participants and monolingual participants on the incongruent trials of the Stroop task, remaining consistent with previous literature. This is due not necessarily to the complexity or of the task, as the results of tests studying central executive function and complexity show mixed results, but due to the added language component of the Stroop task, which acts as a confound (Bialystok, 2017).

H4a: Bilingual participants will have lower EEG signal strength during the critical flicker fusion threshold task relative to monolingual participants.

H4b: Bilingual participants will have lower EEG signal strength during the Landolt C task relative to monolingual participants.

H4c: Bilingual and monolingual participants will not have a significant difference in EEG signal strength during the Stroop task.

Having a lower EEG signal strength would indicate a lower information flow during the task, and would in turn suggest that the group with the lower EEG signal strength did not require as much information flow as the other group to complete the task. The following hypothesized results are summarized graphically below.

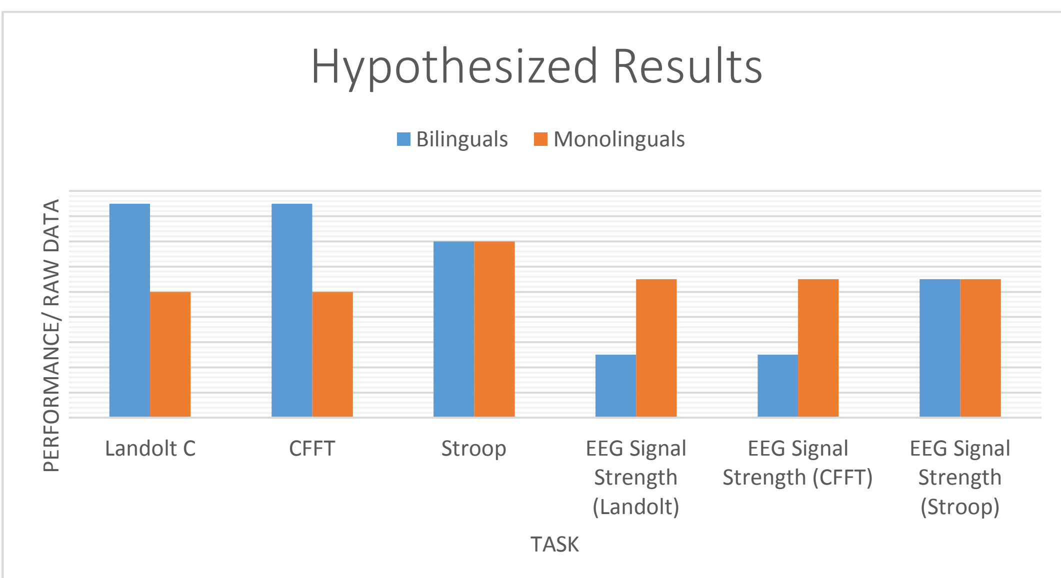

Figure 1. Hypothesized Results by assessment

METHODS

Study Design

The present study is a blinded two-group design that was divided into the two groups after testing had been completed. The design was based off of the work of Drs. Nàñez and Holloway, who the focus of this study was drawn from. This study utilizes two tasks from their previous studies: the Landolt C and Critical Flicker Fusion Threshold task. Added to this study are the Stroop task to act as a distractor between the two perceptual tasks, and an EEG to record all tasks during the study. The Language Assessment Scales (LAS) in English and Spanish are used to determine the language groups.

Measurements

The Landolt C. As psychophysical non-linguistic decoding measure, the Landolt C is presented on a computer program. Participants were presented with the letter C facing one of the four cardinal orientations at three distance points from a central focus point, in one of eight compass points in a circular pattern (See Appendix A). Participants indicated the direction of the opening of the letter C by pressing the corresponding directional key displayed on the screen with the mouse. Percentage correct was recorded for each of the three distances from the focal point across four blocks of 96 trials each, a total of 384 trials.

Critical Flicker Fusion Threshold. The critical flicker fusion threshold (CFFT) was determined using a Macular Pigment Desintrometer. This task involved participants looking through an ocular lens to see a white disc flickering over a blue background. Study staff slowly increases the frequency in which the disc flickers, and asks that the participant indicate the point at which the disc begins to flicker so quickly that it appears to be solid. The frequency is then turned up, and then decreased slowly until the participant perceives the flicker once again. This trial is done three times, for a total of six trials, and then averaged for a numerical value that indicates the subject's CFFT.

Stroop Task. The Stroop task was used from an online cognitive task site, *CognitiveFun.net.* Participants were shown either congruent word-color pairs (e.g. the word depicted was the same as the color it was written in) or incongruent word-color pairs (e.g. the word depicted a color that did not match the color it was written in) in a random order. After 50 trials, the program displayed the average reaction time of each participant for congruent and incongruent trials, as well as the percentage correct. Participants that did not score 100% correct were excluded from the study.

EEG. Prior to beginning any of the psychophysical tasks, participants were fitted with a 20-electrode cap iWorx EEG cap by study staff. Each electrode was tested prior to recording and re-gelled if necessary to ensure optimal recording during all tasks. Participants had EEG waves recorded during the duration of the tasks, and study staff indicated on the EEG recording when each task began and ended for later analysis.

Procedure

24 participants, screened for right and left handedness and eye acuity, were consented to participate in the study. Half of the participants began by taking the Language Assessment Scales (LAS) to assess their ability to understand both the English and Spanish language. Participants, in a counterbalanced order, completed four assessments including listening and reading tasks in each language. Participants that scored a 4 or above in both English and Spanish assessments were classified as bilingual.

Participants that scored below a 3 in Spanish, but a 4 or above in English were classified as monolingual. Any participants that scored a 3 or below on the English assessments were excluded from the study.

The other half of participants began by having an electroencephalograph (EEG) fitted and calibrated appropriately. These participants completed 384 trials of the Landolt C. They then completed 50 trials of the Stroop task. Their CFFT was measured last by a researcher before removing the EEG cap.

All participants completed both the LAS and EEG portions of the study and were not scored to be classified as bilingual or monolingual until after they had completed all tasks and left the lab, leaving all study staff blind to their language ability during all testing procedures. Participants were split up and run in this way to counterbalance the experiment.

Although all electrodes recorded activity during the tasks, only one electrode was chosen to be analyzed for each of the tasks based on the location of the electrode (See Appendix B). For the Landolt C task, the F3 electrode was chosen due to its location between both Broca's area and the frontal lobe. For the Stroop task, the F7 electrode was chosen due to its location in the frontal lobe on the same side of the brain (left) as the F3 electrode used to analyze the Landolt C task. Finally, the central Cz electrode was chosen to analyze the CFFT task due to proximity to central dorsal stream, which is essential in processing this task (Holloway et al., 2014). This was done to ease analysis.

Participants

Recruited participants were 31 adults with ages ranging from 18-38. All participants had normal or corrected-to-normal vision as determined by an on-site Snellen test. Five participants were excluded from the study due a score on the English portion of the LAS that was below a 4. Scores below a 4 on the LAS are consistent with basic understanding of the language, allowing the possibility that the participant might have been unable to adequately understand instructions during the rest of the task. One participant was excluded due to being fluent in a language that was not Spanish or English, which would create a confound in the data. Finally, one participant was excluded due to having a Stroop score below 100% correct. 54% of participants were Male, with 14 classified as monolingual and 10 bilingual. Participants were recruited from Psychology classrooms at Arizona State University's west campus, and bilinguals were specifically requested to participate.

Analysis Approach and Data Preparation

Data from the Landolt C task was exported into an excel sheet, and sorted by each of the three distance points (See Appendix A) and consisted of percent correct at each distance. Percentage by distance was then separated by language group, and analyzed between the groups at all three distances using a two-sample t-test assuming equal variance.

All participants scored at 100% correct for the Stroop task, and had reaction times recorded for congruent and incongruent stimuli, which were also separated by language group. Average reaction times for the incongruent trials were compared between groups using a two-sample t-test assuming equal variance.

CFFT was measured by taking the average of six consecutive measurements of threshold. Thresholds were then separated and averaged as with the two previous tasks.

Values were compared between groups using a two-sample t-test assuming equal variance.

EEG data was analyzed by cleaning the data using LabScribe EEG software by using data collected from two base electrodes. Data points after cleaning are reflective of the original signal subtracting the noise collected from the base electrodes, creating points that are either negative or positive based on the noise of that task. The F7 electrode was selected for data related to the Stroop task, Cz for data related to the CFFT, and F3 for the Landolt C task (See Appendix B for map of electrodes). These electrodes were chosen based on their proximity to related mechanisms in the brain for each task. Data was then selected in 2 second intervals (2000 data points) during the course of each task, and averaged for each participant. Sections were chosen by selected by first taking out sections of highest noise, then by time completing the task (in stepwise fashion by participant number selecting either sections early in the task, in the middle of the task, or toward the end of the task). Data was then separated by task, and analyzed using a two-sample t-test assuming equal variance to compare all data points between tasks.

Variables Defined

As part of the present study, there is one independent variable and four dependent variables that correspond to each of the different tasks and hypotheses. The independent variable, *Language identity,* has two sub-types, bilingual language identity and monolingual language identity. The dependent variables represent the four tests and six hypotheses mentioned previously: *Landolt C performance, critical flicker fusion threshold, incongruent Stroop reaction time,* and *EEG signal strength during the critical* *flicker fusion task, EEG signal strength during the Landolt C task, and EEG signal during the Stroop task.*

Independent Variable

Language Proficiency. (1) Bilinguals: participants that scored a 4 or higher on both the English and Spanish Language Assessment Scales (2) Monolinguals: participants that scored a 4 or higher on the English Language Assessment Scales but a 2 or below on its Spanish counterpart.

Dependent Variables

Critical flicker fusion threshold. A score that corresponds to the frequency at which a disc is flickering, collected using the macular pigment desintrometer that may range from 0 to 50.

Performance on Landolt C task. Three separate percentages corresponding to performance on the Landolt C task at three distances from the central focal point. Percentages are then averaged to retrieve an overall performance score ranging from 0 to 100% correct.

Incongruent reaction time. Reaction time (in ms) from the moment in which the incongruent stimulus from the Stroop task is presented to the moment in which the correct answer is given.

EEG signal strength during the critical flicker fusion, Landolt C, and Stroop tasks. The information flow in the brain used to perform a perceptual task. Signal strength will be collected for each task, allowing for EEG signal strength values for each participant. Values can range from -10 to 10 based on polarity and amplitude.

RESULTS

Analysis

Analysis was done in excel using a two-sample t-test assuming equal variance for each hypothesis with the exception of the EEG signal strength during the critical flicker fusion threshold task, which was determined to have unequal variances by a test of heteroscedasticity, and therefore a two-sample t-test assuming unequal variance was run. The following results include the t-statistic, p-value (approximated from the t-value for each factor), Cohen's d and r^2 for effect size. For each EEG signal strength analysis, one electrode was chosen to present the data from a 20 electrode cap, leading to a low effect size to being expected across these results. Descriptive Statistics shown in Appendix D.

H1 Hypothesis and Results.

Bilingual participants will have a higher Critical Flicker Fusion Threshold than monolingual participants, remaining consistent with previous literature.

Bilingual participants demonstrated a non-significant difference from monolingual participants in critical flicker fusion threshold, $t(22) = -0.17$, $p < 0.87$, $r^2 = .001$, $d = -0.07$. In other words, there was no difference between the critical flicker fusion thresholds of monolingual and bilingual participants.

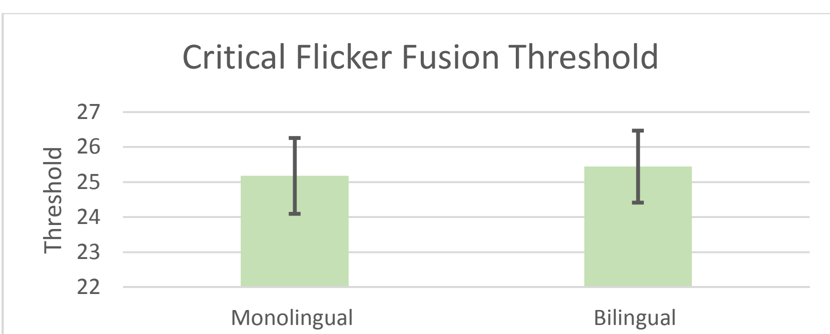

Figure 2. Critical Flicker Fusion Threshold values between Bilingual and monolingual. Error bars represent standard errors.

H2 Hypothesis and Results.

Bilingual participants will show better performance on the Landolt C task relative to monolingual participants.

Bilingual participants demonstrated a non-significant difference from monolingual participants in Landolt C performance, t (70) = 0.29, $p < 0.77$, $r^2 = .001$, d = 0.06. In other words, there was no difference on the performance of the Landolt C task between monolingual and bilingual participants.

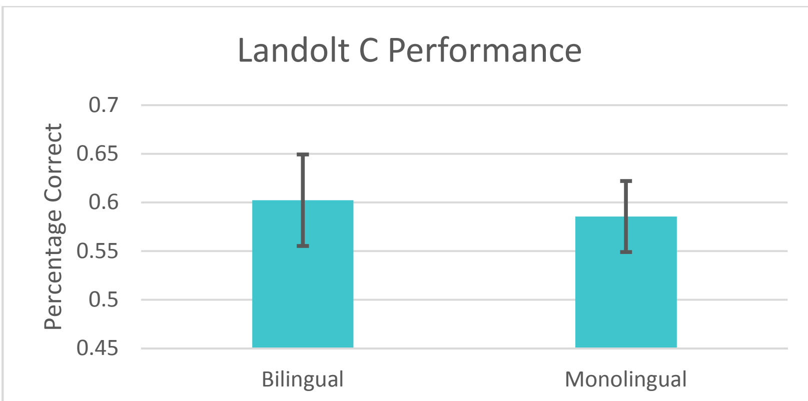

Figure 3. Performance on the Landolt C task between monolingual and bilingual participants. Error bars represent standard errors.

H3 Hypothesis and Results.

There will be no statistical differences between bilinguals and monolinguals on the incongruent trials of the Stroop task.

Bilingual participants demonstrated a non-significant difference from monolingual participants in reaction time during the incongruent trials of the Stroop task, t(70) = 0.29, $p < 0.77$, $r^2 = 0.12$, d = -0.70. In other words, there was no difference on the reaction time during the incongruent trials of the Stroop task between monolingual and bilingual participants.

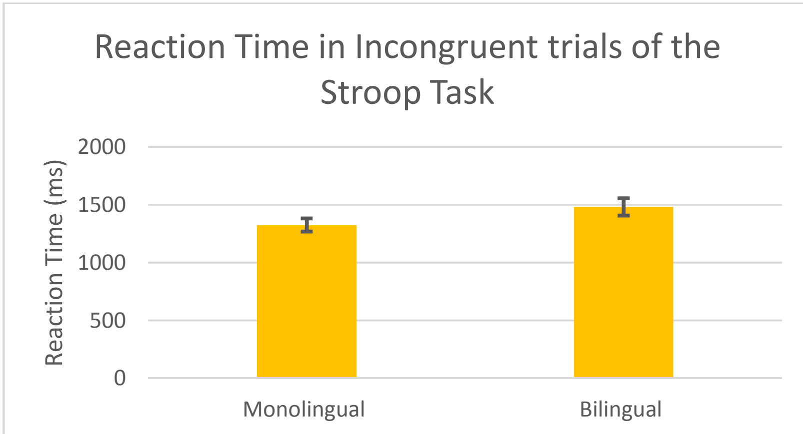

Figure 4. Reaction time between bilinguals and monolinguals on the incongruent trials of the Stroop task. Error bars represent standard errors.

H4-A Hypothesis and Results.

Bilingual participants will have a lower EEG signal strength during the critical flicker fusion threshold task relative to monolingual participants.

Bilingual participants demonstrated a significant difference from monolingual participants in EEG signal strength during the critical flicker fusion threshold task, t (47998) = 2.27, p = .02, r^2 = .016, d = 0.09. In other words, on average bilingual participants had a higher EEG signal strength during the critical flicker fusion threshold task relative to monolingual participants. The variance between these two groups were statistically significant, F_{MAX} = 17.4.

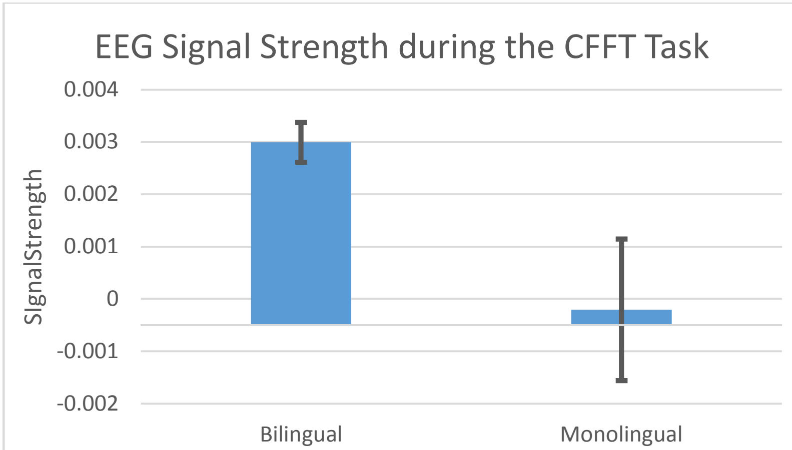

Figure 5. EEG Signal Strength between Bilinguals and Monolinguals during the CFFT Task. Error bars represent standard errors.

H4-B Hypothesis and Results.

Bilingual participants will have a lower EEG signal strength during the Landolt C task relative to monolingual participants.

Bilingual participants demonstrated a significant difference from monolingual participants in EEG signal strength during the Landolt C task, $t\ (47998) = -4.87$, $p < .001$, $r^2 = .0005$, $d = -0.05$. In other words, on average bilingual participants have a lower EEG signal strength relative to monolingual participants.

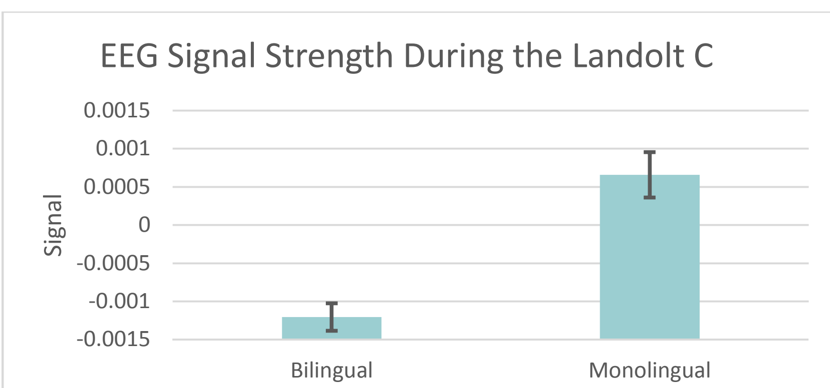

Figure 6. EEG signal strength between bilinguals and monolinguals during the Landolt C task. Error bars represent standard errors.

H4-C Hypothesis and Results.

Bilingual and monolingual participants will not have a significant difference in EEG signal strength during the Stroop task**.**

Bilingual participants demonstrated a significant difference from monolingual participants in EEG signal strength during the Stroop task, t(47998) = 20.04, $p < .001$, $r^2 = .008$, d = 0.19. In other words, on average bilingual participants had a higher EEG signal strength during the Stroop task relative to monolingual participants.

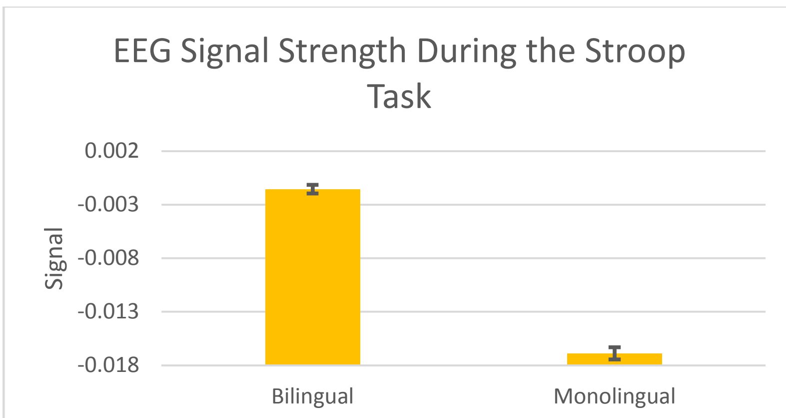

Figure 7. EEG signal strength between bilinguals and monolinguals during the Stroop task. Error bars represent standard errors.

DISCUSSION

By using the EEG to track the electrical activity of the brain, the present study sought to understand why bilingual individuals might have an advantage over monolingual individuals when it comes to tasks that involve perceptual processing. To shed light on this question, bilingual and monolingual participants completed two tasks that required perceptual processing, and one that utilized both language and the central executive. Results in performance on the tasks as well as EEG signal were mixed, and are summarized and discussed.

Performance in Perceptual and Executive Processing Tasks

The perceptual processing tasks, CFFT and the Landolt C, in previous research have shown to be a part of the argument for a bilingual advantage (Holloway et al. 2017). In the present study, however, both showed no statistically significant difference between bilingual and monolingual participants, rejecting the first two hypotheses. For the Landolt C, variability was high (see Appendix D for tables), possibly due to the three different distance points in the task. Overall, participants are usually fairly accurate (around 90% correct) at the closest distance point, and decrease to 30% or lower correct at the farthest distance point. This variability in scores creates a high variability for each participant, which could cause any present effect to be hidden. Statistical analyses for CFFT also showed high variability, which could be due to human error in adjusting frequency during the task or individual differences in vision.

There is mixed evidence to support an advantage for bilingual individuals in research studying the central executive (Solveri et al., 2011). In bilingualism literature, the Stroop task is considered to be an especially confounding task due to its linguistic component (Bialystok, 2007). As expected, bilingual and monolingual participants in the present study did not show a statistically significant difference in their reaction times during incongruent trials of this task, remaining consistent with the literature.

EEG Signal Strength during Perceptual and Executive Processing Tasks

During completion of the Landolt C, CFFT, and Stroop tasks, a 20-electrode EEG cap recorded the electrical brain activity of all the participants. For analysis, 2000 data points were pulled from the portion of data that was collected during the critical flicker fusion threshold task for each part. The data from this task showed that there was a statistically significantly higher EEG signal for bilingual participants relative to monolingual participants, meaning that bilingual participants used significantly more energy to complete this task relative to monolingual participants. Statistics also show, however, that there is a significant difference in the variability between the two groups, which were both high. This is most likely due to EEG data having a significant amount of noise (interference that is usually movement) during collection. While performing tasks that fatigue the eyes such as CFFT, participants might blink, squint or lean more often than during tasks that do not rely as much on vision, possibly contributing to the noise and variability in the data. Sample size is also a very significant limitation. In the present study there were a total of 24 participants, which is very small and has very lower power to see an effect.

Like the CFFT, 2000 data points were pulled from the EEG recording that was collected during the Landolt C task for each part. The data collected from this task showed that bilingual participants used significantly less energy to complete the Landolt C task than monolingual participants. Having a lower amount of energy expended to complete a task shows the possibility of higher efficiency in electrode networks in areas used to process that task (He et al., 2009; Duong et al., 2005).

EEG recording during the Stroop task showed that monolingual participants expended significantly less energy during the task relative to bilingual participants. While this rejects the final hypothesis that there would be no difference in the EEG signal strength between the two groups during the Stroop task, this result stands consistent with literature that verbal and linguistic tasks are confounding to bilingual individuals (Kousaie & Phillips, 2012), and that there are higher switching costs in the frontal lobe for bilingual individuals than monolingual individuals (Gold et al., 2013). This explanation remains consistent with higher energy expenditure for bilingual participants.

Study Limitations and Future Directions

When interpreting the results of the present study, it is important to note that the effect sizes for all statistical analyses are very low. In analyses involving EEG signal strength, there is high power (df = 47998 in each analysis), but low effect size, meaning that there must be a very high power to see significance. Also contributing to the low effect size is the analysis, which used only one electrode per task from a 20-electrode EEG cap. EEG caps can hold over 100 electrodes to increase the power and spatial resolution, which was not used in this study due to availability. Values for signal strength in EEG were derived by factoring out noise collected by base electrodes, which often had noise high enough to turn values negative.

A low sample size (24 participants) contributes greatly to the low effect size and power of the analyses in the first three hypotheses concerning performance on psychophysical tasks. In perceptual processing research, it is more typical to use a minimum of 100 participants, which this study was unable to do.

These limitations should be considered for future research, such as using EEG systems that can derive more data with more complex analyses involving multiple electrodes and less noise, and larger sample size. Future research would be benefitted as well from using EEG to detect the direction and magnitude of information flow to study the collaboration of different cortical areas, and determine the magnitude of competing attention often attributed to bilinguals in the frontal lobes (Kroll et al., 2012; Kroll et al., 2014).

To study information flow and localization of information as mentioned by the study of intelligence in research by Thatcher et al., (2016), future analysis should be done to study the addition of an electrode in the pre-frontal cortex. By comparing complexity and signal strength in the electrodes chosen in this study to a pre-frontal cortex electrode in bilingual and monolingual participants, a case can be made to determine if the finding that those with high IQ's utilizing less collaboration and more localization between cortical areas relative to those with average IQs parallels that of bilingual and monolingual populations.

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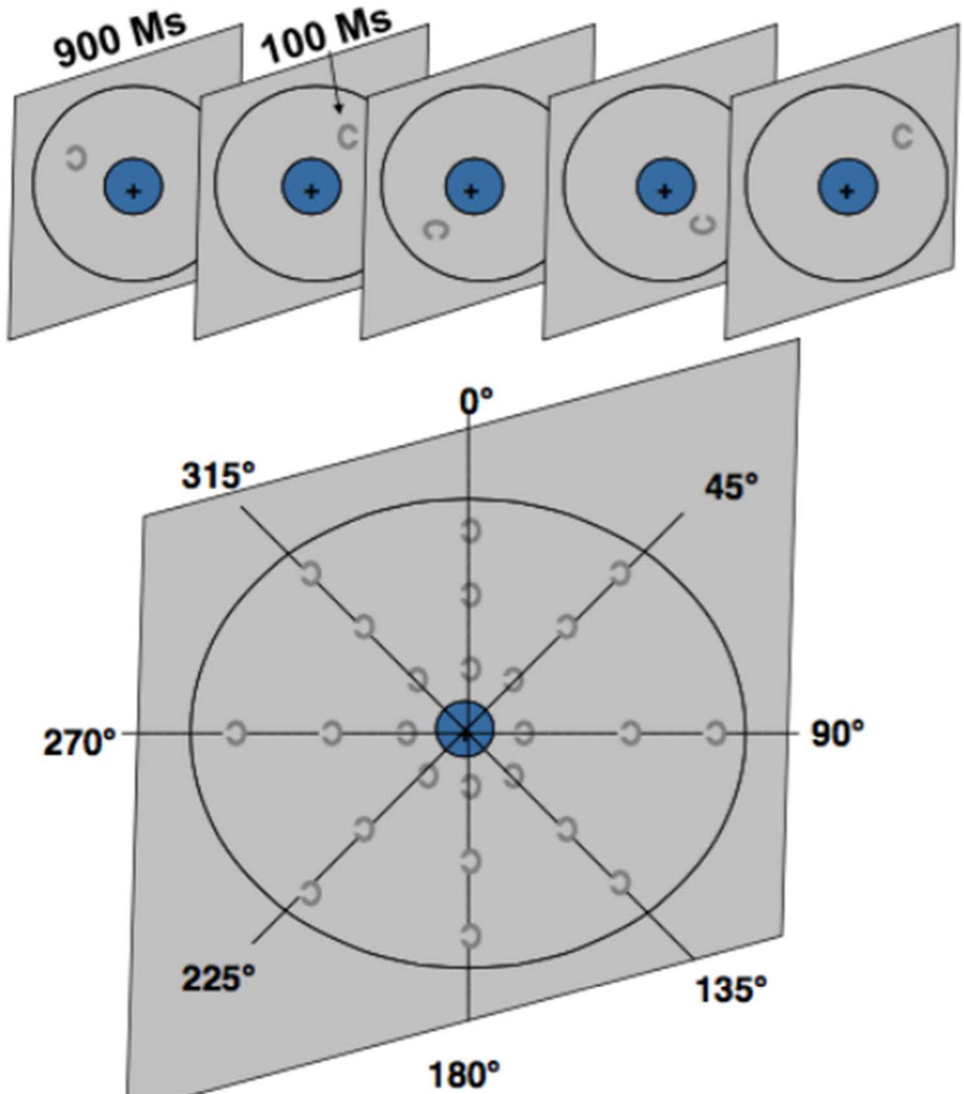
APPENDIX A

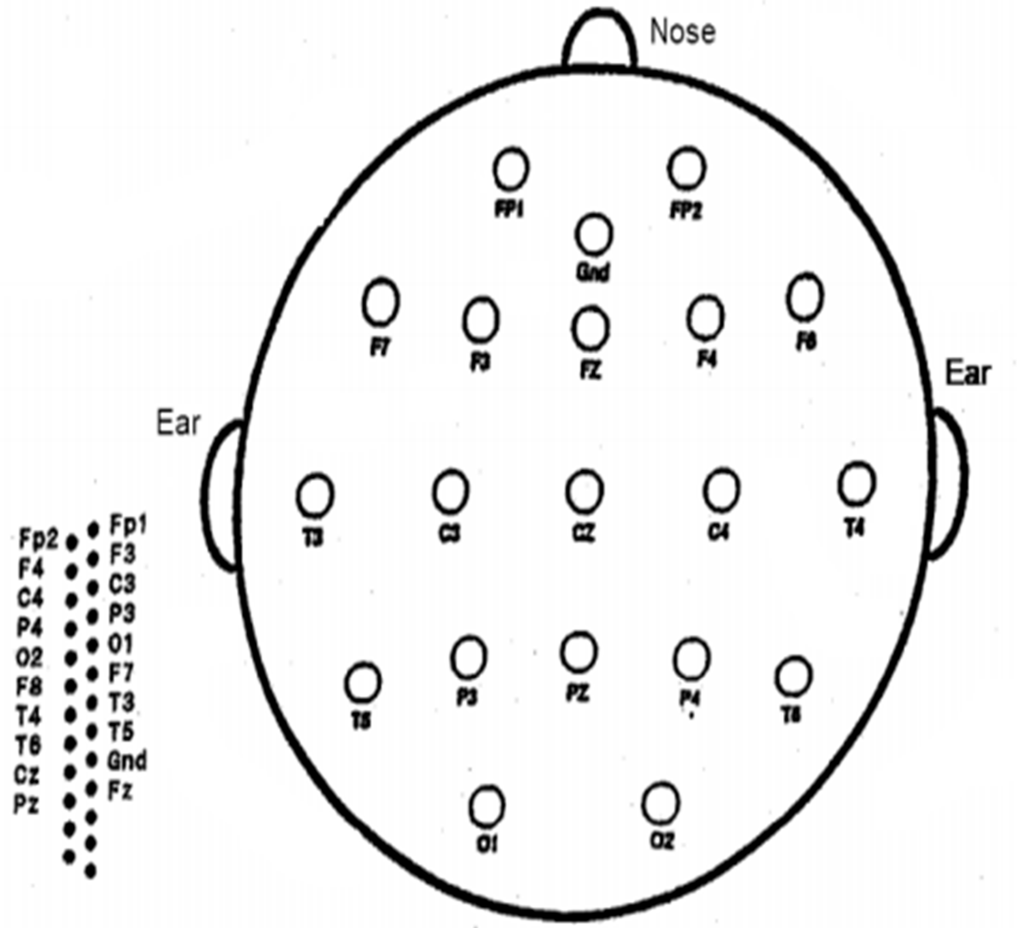
LANDOLT C



Trials comprise Landolt C targets presented 3 distances from the focus point for the eight cardinal and inter-cardinal directions. 4 Cardinal orientations will be presented randomly for the Landolt C targets.

APPENDIX B

EEG ELECTRODE MAP


Nose
FP1
FP2
Gnd
F7
F3
FZ
F4
F8
Ear
Ear
T3
C3
CZ
C4
T4
T5
P3
PZ
P4
T6
O1
O2
Fp2 F4 C4 P4 O2 F8 T4 T6 Cz Pz
Fp1 F3 C3 P3 O1 F7 T3 T5 Gnd Fz

APPENDIX C

LANGUAGE ASSESSMENT SCALES

Mark your answer.

Pause to let the students mark their answer.

☐ **NUMBER 3**

SAY* NUMBER 3. From the map, list all rivers and streams that empty into the bay. What were you told to do?

A. Draw a map of all the water systems.

B. Add the names of the rivers on the map.

C. Use the map to make a list of the rivers.

Mark your answer.

Pause to let the students mark their answer.

☐ **NUMBER 4**

SAY* NUMBER 4. Give your name to the photographer's assistant. Then stand in this line to have your photo taken. What were you told to do?

A. Hand the photographer your school photo.

B. Assist the photographer in taking school photos.

C. Give your name and stand in line to be photographed.

Mark your answer.

Pause to let the students mark their answer.

☐ **NUMBER 5**

SAY* Look at the next page.

Pause.

SAY* NUMBER 5. Each runner will do four laps on the track, followed by ten pushups. What were you told to do?

A. Do ten pushups or run four laps.

B. Watch four runners doing pushups.

C. Run four times around the track and do ten pushups.

Mark your answer.

Pause to let the students mark their answer.

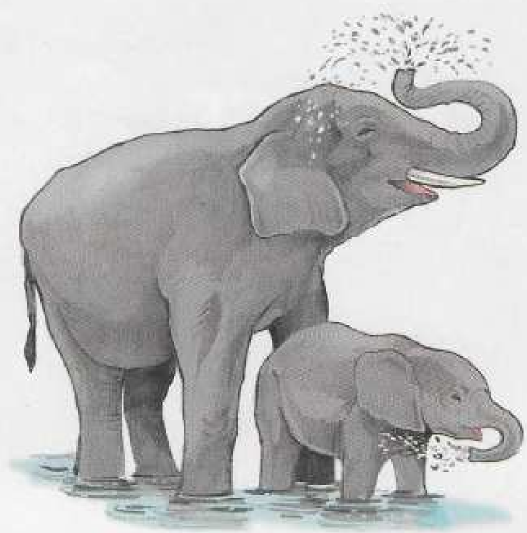
Directions: Read the article. Then do Numbers 26 through 31.

The Social Behavior of Elephants

When we hear the word "society," we naturally think of people living and working together, but scientists tell us that some animals also live in societies. Animal researcher Cynthia Moss says that elephants have a very complex society. According to Moss, elephants may have the largest social network of any land mammal after humans. That means generations of family members will stay together, sharing resources and responsibilities.

An elephant family consists of the adult females and their newborns. When a male elephant reaches adulthood, he will leave the family group and live with other grown males. About twelve elephants make a family group, which is led by the oldest female. When the group gets too large, some members will form a new one. But these family groups will continue to work together sharing food and water. In this large social network, an elephant can recognize two hundred other elephants in its society.

At times, the behavior of elephants resembles the way we interact in our society. Just as people greet each other by shaking hands or hugging, elephants also greet each other by grabbing trunks. They use tools, which is very rare among animals. An elephant will pick up a stick with its trunk to scratch an itch. They have even been observed grieving over family members who have died.



Mark your answer.

Pause to let the students mark their answer.

☐ **NUMBER 3**

SAY* NUMBER 3. From the map, list all rivers and streams that empty into the bay. What were you told to do?

A. Draw a map of all the water systems.

B. Add the names of the rivers on the map.

C. Use the map to make a list of the rivers.

Mark your answer.

Pause to let the students mark their answer.

☐ **NUMBER 4**

SAY* NUMBER 4. Give your name to the photographer's assistant. Then stand in this line to have your photo taken. What were you told to do?

A. Hand the photographer your school photo.

B. Assist the photographer in taking school photos.

C. Give your name and stand in line to be photographed.

Mark your answer.

Pause to let the students mark their answer.

☐ **NUMBER 5**

SAY* Look at the next page.

Pause.

SAY* NUMBER 5. Each runner will do four laps on the track, followed by ten pushups. What were you told to do?

A. Do ten pushups or run four laps.

B. Watch four runners doing pushups.

C. Run four times around the track and do ten pushups.

Mark your answer.

Pause to let the students mark their answer.

19 Según el texto, ¿por qué las ballenas azules son consideradas mamíferos y vertebrados?

A Tienen sangre caliente y columnas vertebrales.

B Se pueden comunicar con otras ballenas azules.

C Sus lenguas son muy similares a las de los elefantes.

D Sus crías crecen rápidamente las primeras semanas de vida.

20 ¿Cuál es la idea PRINCIPAL del párrafo 2?

F Las ballenas azules son más grandes que otros tipos de ballenas.

G Las ballenas azules tienen un tamaño y peso espectacularmente grande.

H Las ballenas azules necesitan un corazón grande para mantener su gran cuerpo.

J Las ballenas azules viven en el agua porque su gran tamaño no puede ser sostenido en la tierra.

21 Lee esta oración del texto.

Una de las características más fascinantes de las ballenas azules es su capacidad de emitir los sonidos más fuertes del planeta.

¿Qué significa emitir en la oración?

A distinguir

B escuchar

C interpretar

D producir

22 Lee esta oración del texto.

Luego de un período de gestación de un año, una cría de ballena azul nace con un peso de alrededor de tres toneladas y una longitud de 25 pies (8 metros).

¿Qué significa gestación en la oración?

F crecimiento

G desarrollo

H observación

J transacción

CONTINÚA

APPENDIX D

DESCRIPTIVE STATISTICS

Criticial Flicker Fusion Threshold Performance

t-Test: Two-Sample Assuming Equal Variances

	Monolingual	*Bilingual*
Mean	25.17785714	25.444
Variance	16.37571044	10.56089333
Observations	14	10
Pooled Variance	13.99692162	
Hypothesized Mean Difference	0	
df	22	
t Stat	-0.171813366	
P(T<=t) one-tail	0.432577448	
t Critical one-tail	1.717144374	
P(T<=t) two-tail	0.865154896	
t Critical two-tail	2.073873068	

Landolt C Performance

t-Test: Two-Sample Assuming Equal Variances

	Bilingual	*Monolingual*
Mean	0.602333333	0.585488095
Variance	0.066470986	0.055705555
Observations	30	42
Pooled Variance	0.06016552	
Hypothesized Mean Difference	0	
df	70	
t Stat	0.287291213	
P(T<=t) one-tail	0.387369055	
t Critical one-tail	1.666914479	
P(T<=t) two-tail	0.77473811	
t Critical two-tail	1.994437112	

Stroop Task incongruent trial Results

t-Test: Two-Sample Assuming Equal Variances

	Monolingual	*Bilingual*
Mean	1325.410714	1481.687
Variance	43647.94168	57177.93373
Observations	14	10
Pooled Variance	49182.93843	
Hypothesized Mean Difference	0	
df	22	
t Stat	-1.701939985	
P(T<=t) one-tail	0.051428906	
t Critical one-tail	1.717144374	
P(T<=t) two-tail	0.102857811	
t Critical two-tail	2.073873068	

EEG Signal Strength during Criticial Flicker Fusion Threshold

t-Test: Two-Sample Assuming Unequal Variances

	Bilingual	*Monolingual*
Mean	0.002993049	-0.000208263
Variance	0.002954045	0.051427362

(assuming unequal variances)

Observations	20000	28000
Hypothesized Mean Difference	0	
df	32390	
t Stat	2.272553436	
P(T<=t) one-tail	0.011529814	
t Critical one-tail	1.644900673	
P(T<=t) two-tail	0.023059627	
t Critical two-tail	1.960037228	

EEG Signal Strength during Landolt C

t-Test: Two-Sample Assuming Equal Variances

	Bilingual	*Monolingual*
Mean	-0.001206036	0.000657828
Variance	0.000641414	0.002469516
Observations	20000	28000
Pooled Variance	0.001707813	
Hypothesized Mean Difference	0	
df	47998	
t Stat	-4.871553664	
P(T<=t) one-tail	5.55381E-07	
t Critical one-tail	1.644885374	
P(T<=t) two-tail	1.11076E-06	
t Critical two-tail	1.96001341	

EEG Signal Strength during Stroop Task

t-Test: Two-Sample Assuming Equal Variances

	Bilingual	*Monolingual*
Mean	-0.001528929	-0.016894775
Variance	0.003291385	0.009403365
Observations	20000	28000
Pooled Variance	0.006856728	
Hypothesized Mean Difference	0	
df	47998	
t Stat	20.04340033	
P(T<=t) one-tail	2.66963E-89	
t Critical one-tail	1.644885374	
P(T<=t) two-tail	5.33926E-89	
t Critical two-tail	1.96001341	