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Comparative Morphological Processing in Adult Chinese-English Bilinguals: Insights from ERP and Electrophysiological Responses

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Abstract

Morphology, or the study of the form of words, is an important aspect of the human language. However, the ways in which human neural bases process morphology is yet to be fully understood as. This paper focuses on replicating and extending the findings of (Gao et al., 2023), which explored the similarities and differences of morphological processing between the first and second language of adult Chinese-English bilinguals.

Bilingual participants completed a morphological priming lexical decision task, which drew on derivational morphology, something that both Chinese and English share. Researchers then recorded their electrophysiological and optical responses concurrently. Neural dissociations exist between morphological and semantic priming effects between language.

At the start of lexical processing, early left anterior negativity (ELAN) effect demonstrated that there was a difference in cross-language morphological processing in terms of degree, not in kind. We used data from the original study to generate graphs that indicated the event-related potential (ERP) of speakers.

The results collected from this study have created a unified competition model for bilingual development. This model suggests that bilinguals typically employ first language neural resources, and use second languages for morphological representation and processing.

Keywords: morphological processing, Chinese-English, bilinguals, ERP, EEG, prefrontal

Introduction

Representing the external world in symbols, language is central to human cognition as we use it to communicate and think. Morphology, on the other hand, is an important aspect of the human language system that indicates how we form words and interconnections within a language. Morphological typology categorizes world languages based on their word formation methods. For example, as a morpho-syllabic language, Chinese relies on compounding (more than 70%) for word formation instead of inflections. English is a weak inflectional language that constitutes limited word form changes. Morphology and word structure information are an important implication in the processing stage, language comprehension, and production processes (Levelt, 1993). Given that there are distinct morphological differences between Chinese and English, there is evidence to suggest that the processing of these languages also differs.

Previous literature has identified several regions for language processing. Historically, Broca's area and Wernicke's area have long been recognized as regions responsible for speech production and comprehension (Friederici, 2015). Additionally, fMRI studies have also identified the left prefrontal and temporal areas as key regions of interest (Binder et al., 1997; Rueckert et al., 1994). The same conclusion has also been supported by studies using other imaging techniques, including EEG, MEG, etc. (Bolte et al., 2009; Fruchter et al., 2013).

Many effects of morphological processing have already been identified by past EEG studies. Left anterior negativity, the occurrence of a negative waveform over the left hemisphere, has been widely observed in linguistic processing. Specifically, Bölte, et al. (2009) demonstrated brain potentials with morphological manipulations in German-derived adjectives, using the observed left anterior negativity (LAN) as indicators of sensitivity to (morpho)syntactic errors, including structural difficulty resolution and morphological parsing. Similarly, Gao, et al. (2023) recognized N400 and LAN effects associated with semantic and morphological constraints in Chinese native speakers reading compound words, legal, and illegal nonwords.

However, our knowledge about how bilingual brains process languages is limited (Gao et al., 2023). Researchers have tried to address this issue by studying highly proficient bilinguals and focusing on language structures that are shared between L1 and L2. For instance, a study looked at brain patterns in Finnish (L1) and Swedish (L2) in proficient Finnish-Swedish bilinguals during a language task. The study found distinct brain patterns for bilingual morphology (Lehtonen et al., 2009). On the other hand, some research suggests that the brain mechanisms used for L2 language structure are borrowed from the L1 system when both languages share similar structures (Tolentino & Tokowicz, 2011). These conflicting results point toward a major problem: indeed, do the first and the second language recruit the same neural resources or do they participate in different strategies?

To address the problem, we will acquire EEG data from an existing study on Chinese and English bilinguals, and perform ERP analysis on the frontal-parietal regions to investigate the effect of language on neural activation. We will first replicate the original study and reveal the similarities and differences in English and Chinese processing (Gao et al., 2023). Apart from what has already been demonstrated in the original data set, we will shift our focus to the frontal region, further hypothesizing that bilinguals have greater neural activation using their second language as they will be recruiting more resources to understand a relatively unfamiliar language.

Replication Methods

Our data was retrieved from a study in which brain activity was recorded using EEG and fNIRS (Gao et al., 2023). In this study, there were thirty native Mandarin-Chinese speakers who were recruited from the University of Macau, including 15 males. The participants had a mean age of 22.2 years (*SD* = 3.2) and an age range of 18-30 years. These participants were given words that were primed by corresponding root words. Then participants were instructed to perform a task to judge if a word is people-related or not. There were four conditions, Chinese morphological priming, Chinese semantic priming, English morphological priming, and English semantic priming.

The EEG data was recorded using Brainvision's acti-Camp system while participants were performing lexical tasks. And Brainvision's acti-Camp system is a sophisticated tool that is used for conducting EEG research and is often used in cognitive neuroscience and clinical research. The Brainvision's acti-Camp system had 32 active electrodes, which means that 32 electrodes were able to receive a strong signal. The system could record brain activity 500 times a second (500Hz). The reference point for the measurements was near the left ear. When receiving a brain signal, each electrode was kept below 25 kΩ which is necessary for good quality data. The EEG data collected was pre-processed using a MATLAB tool, EEGLAB. The EEG data was filtered to include only relevant frequencies, between 0.01-30 Hz. A technique called Independent Component Analysis (ICA) was used to identify and remove unwanted noise from the data, such as eye blinks or electrical noise from the environment. Outliers such as wave signals that were too strong or unusual (exceeding ±100 μV) were considered errors and removed. If any particular electrode consistently gave bad data, its data would be estimated based on the average data from surrounding sensors.

An ERP is a technique used to assess brain activity in response to certain stimulation of the senses. Event-related potentials are certain events that occur within the continuous EEG data that are looked at when they are of experimental interest. To perform the ERP analysis, we used the MNE-Python package to access the EEG data. The data was then concatenated and averaged to produce ERPs for each combination of channels, language, and experimental conditions. We were unable to process parts of the data as they are written in a peculiar way that forbids us from concatenating them.

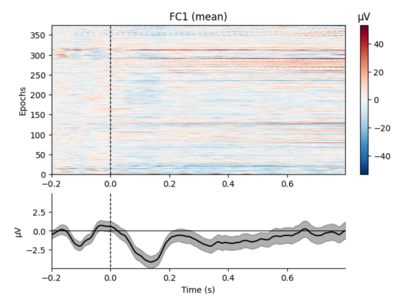
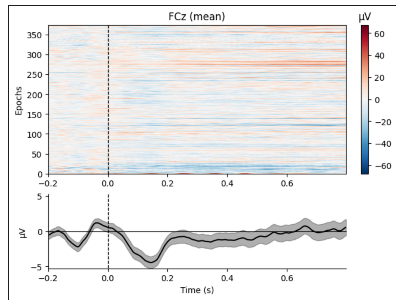
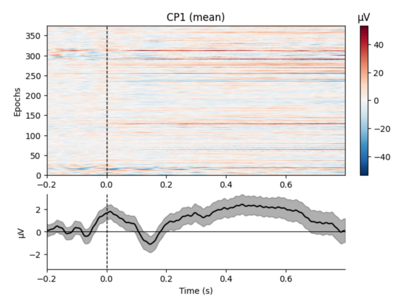
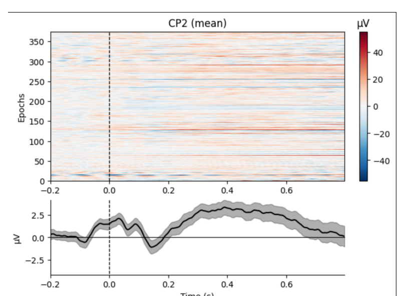
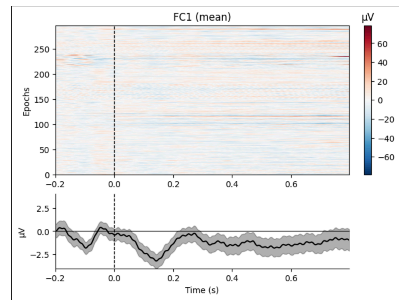
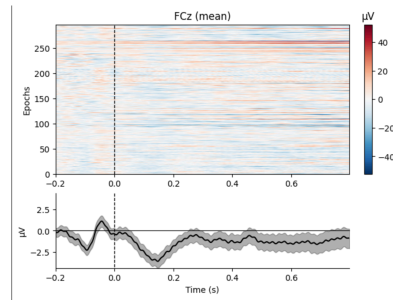
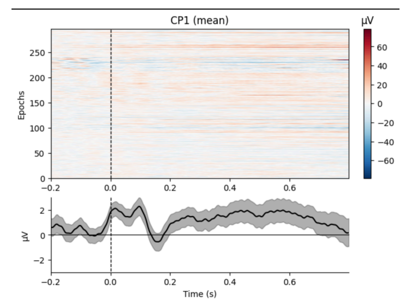
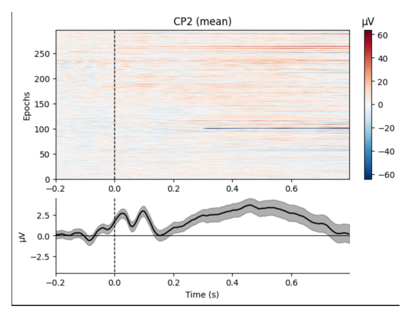
Replication Results

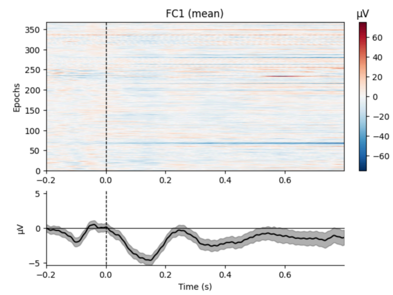
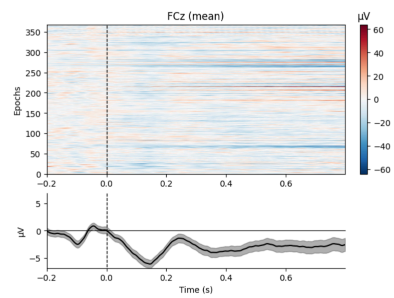
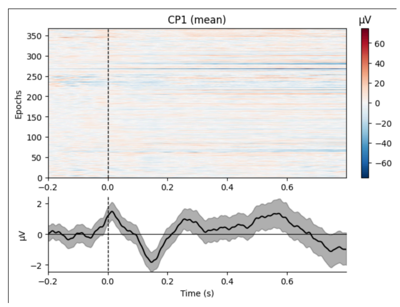
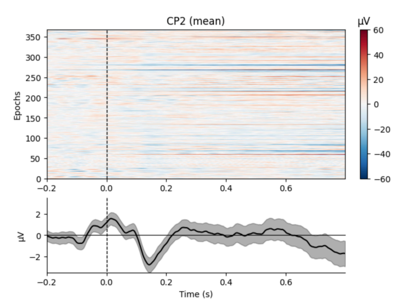
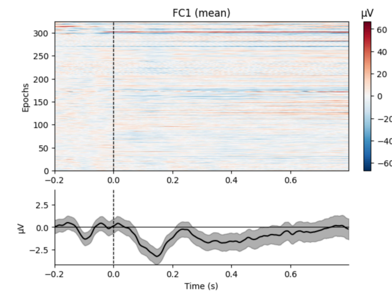
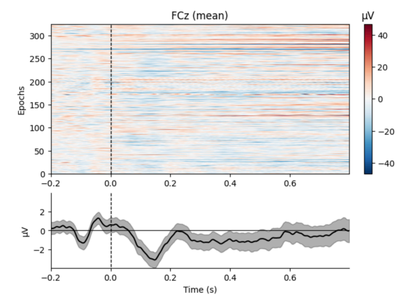
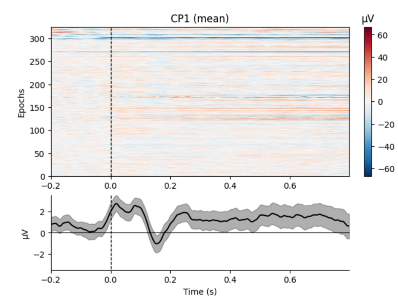
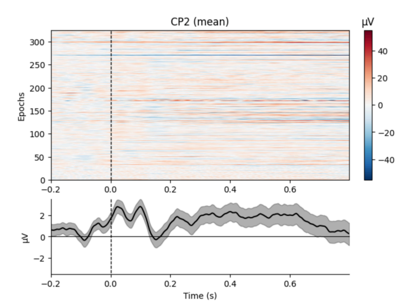
The graphs below are the ERP analysis from some anterior sites, which all exhibit the ELAN effect with a great negativity at around 0.2 second. Such an effect is observed in both L1 and L2, which confirms the original study's conclusion that bilinguals use similar strategies to process different languages. Beside the similarities in the general shape of these ERP waveforms, we also observe the difference of two languages: while the waves often follow the same trend, they may vary in values. This, again, supports the original study's analysis that bilinguals also employ distinct neural circuits when processing different languages.

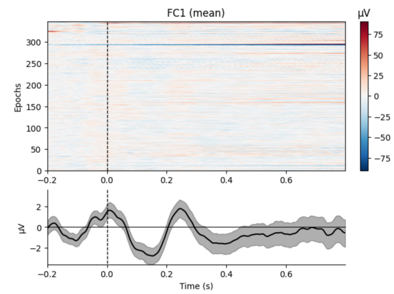
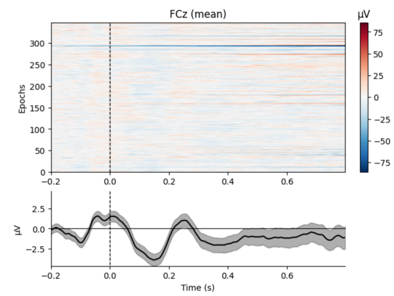
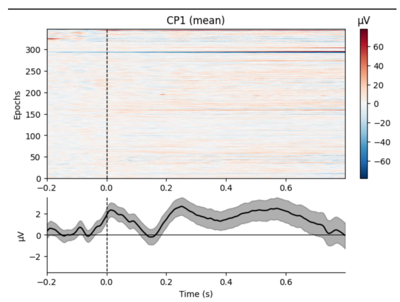
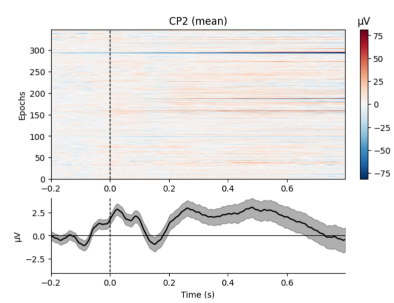
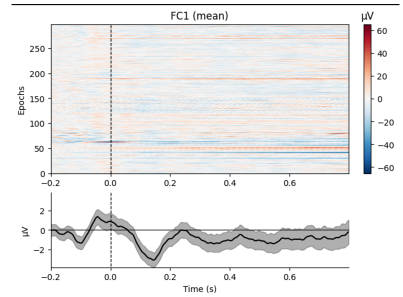
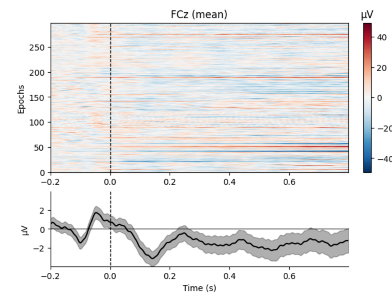
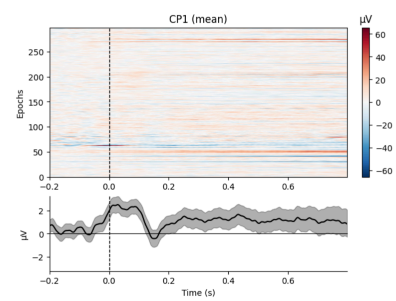
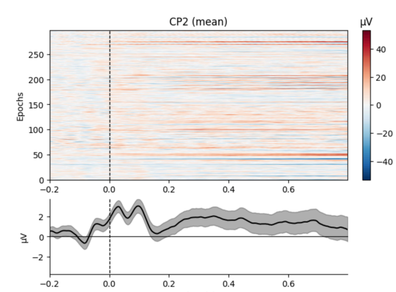
Fig 1

Replicated ERP graphs from EEG data

	Chinese	**English**
Morphological People-related	**Electrode: FC1**	**Electrode: FC1**

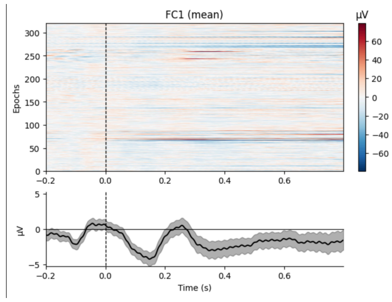
	 **Electrode: FCz**  **Electrode: CP1**  **Electrode: CP2** 	 **Electrode: FCz**  **Electrode: CP1**  **Electrode CP2** 
Morphological **Non-people-related**	**Electrode: FC1**	**Electrode: FC1**

	 **Electrode: FCz**  **Electrode: CP1**  **Electrode: CP2** 	 **Electrode: FCz**  **Electrode: CP1**  **Electrode CP2** 
Semantic People-related	**Electrode: FC1**	**Electrode: FC1**

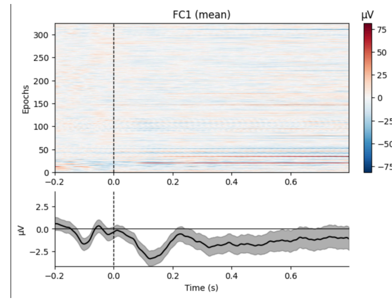
	 **Electrode: FCz**  **Electrode: CP1**  **Electrode: CP2** 	 **Electrode: FCz**  **Electrode: CP1**  **Electrode CP2** 

Semantic Non-people-related

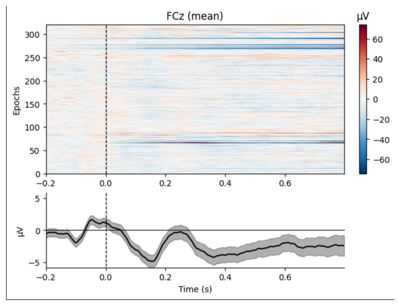
Electrode: FC1



Electrode: FC1



Electrode: FCz



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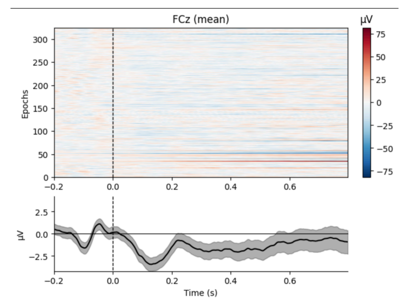
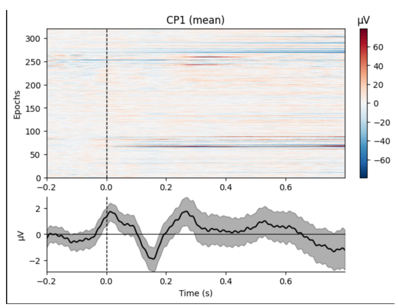
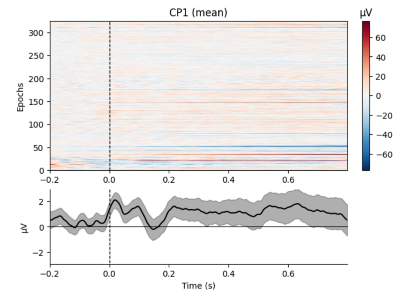


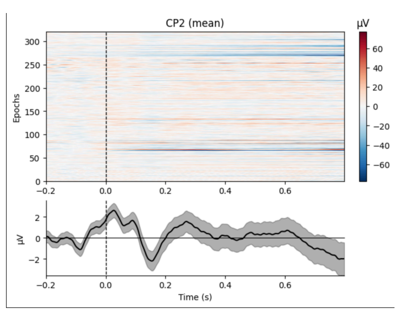
Electrode: CP1



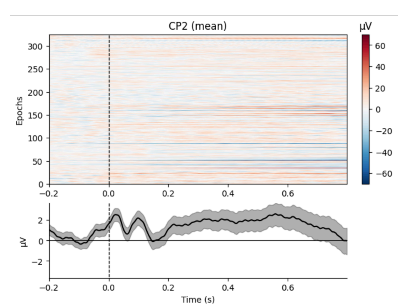
Electrode: CP1



Electrode: CP2



Electrode CP2



Extension Methods

Our extension primarily focuses on examining the impact of language processing on the frontal regions of bilingual brains. To begin, key areas affected by language processing were identified, such as Wernicke's Area, Broca's Area, and the prefrontal cortex, drawing upon relevant literature. Subsequently, electrodes were mapped to those areas based on diagrams provided in the original paper. Utilizing the open dataset, Event-Related Potentials (ERPs) were filtered by the selected electrodes and an ERP graph was generated by employing methodologies consistent with those of the original authors, and as outlined in our replication study (Gao et al., 2023). The same procedure was used to perform the ERP analysis.

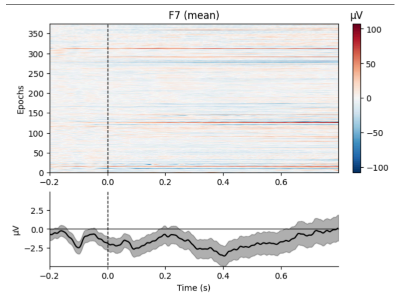
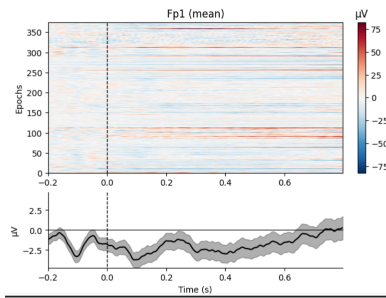
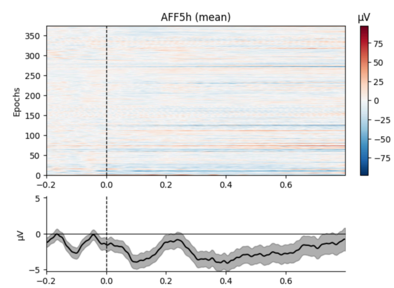
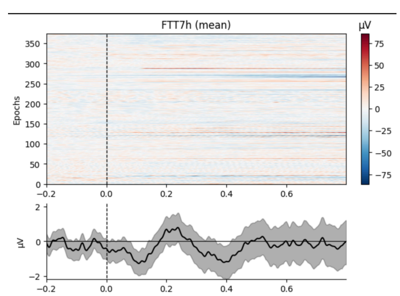
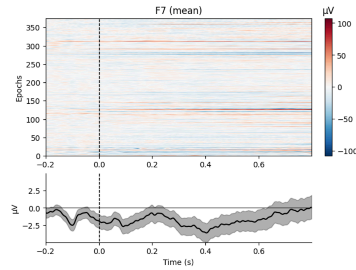
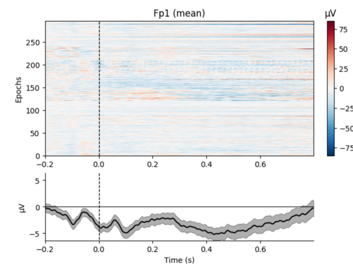
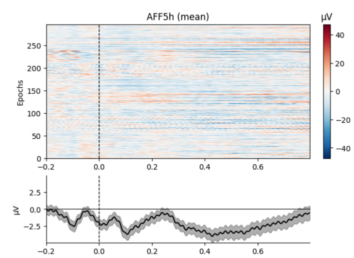
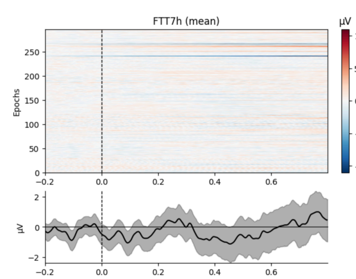
Extension Results

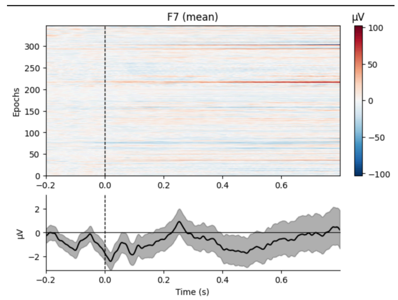
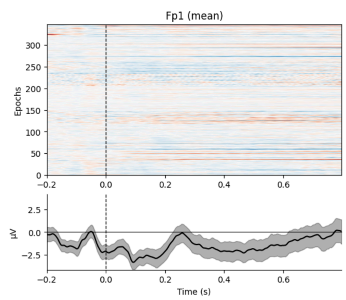
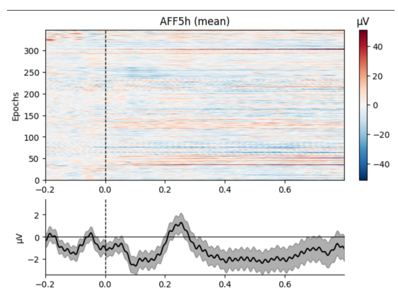
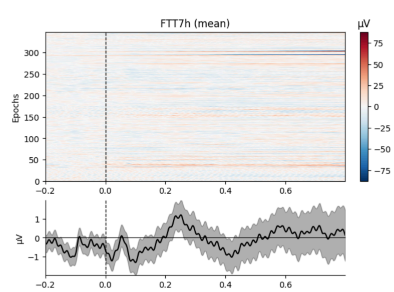
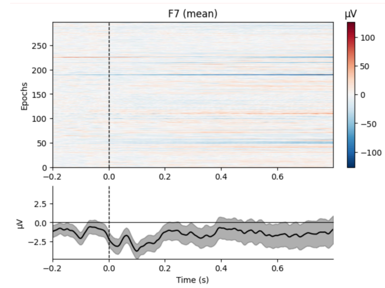
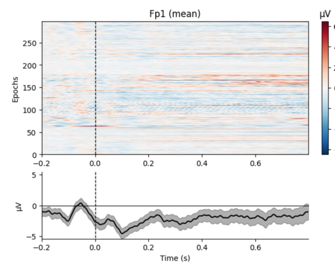
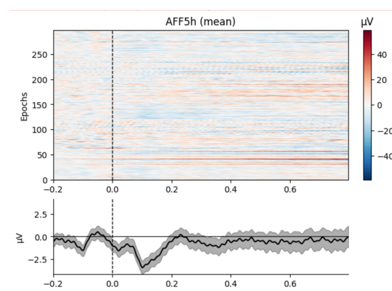
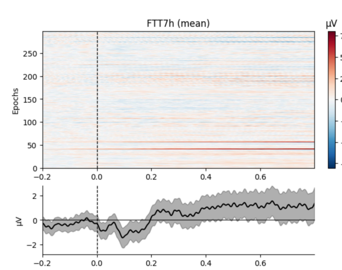
Across the various graphs, the general pattern for each electrode for Chinese and English morphological processing was that the ERPs tended to follow the same trend. And while they were similar, shown in Fig 1., the Chinese graphs tended to have more variance to it than the English graphs, which stayed more level in morphological cases. There were only a few cases where the graphs didn't follow a similar trend and that occurred in the case of semantics, one specific example being Fig 2. The ERPs did not follow a similar trend in this case as there are peaks that occur in the more varied Chinese graphs as opposed to the English graphs.

Fig 2

ERP graphs from EEG data in the prefrontal cortex for F7, FP1, AFF5h, FTT7h electrodes

	Chinese	**English**

Morphological People-related	**Electrode: F7**  **Electrode: Fp1**  **Electrode: AFF5h**  **Electrode: FTT7h**  	**Electrode: F7**  **Electrode: FP1**  **Electrode: AFF5h**  **Electrode: FTT7h** 

Semantic People-related	**Electrode: F7**  **Electrode: FP1**  **Electrode: AFF5h**  **Electrode: FTT7h**  	**Electrode: F7**  **Electrode: FP1**  **Electrode: AFF5h**  **Electrode: FTT7h** 

Discussion

Our hypothesis that bilinguals may exhibit greater neural activation when using their second language was not supported by the current data. Instead, the graphs indicated that the differences in neural activation for each language were only slight, lacking statistical significance. The similarity in the patterns suggests that the same resources are used for each respective language, confirming the replication findings.

It was also observed that variations in the findings among semantic processing are greater than those found in morphological processing. This may be attributed to the fact that semantic processing is more tedious and straining to perform than morphological processing. Therefore, it uses more resources, aligning with the observations.

Limitations

As the data was collected through EEG, while providing a high temporal resolution, the data is poor in spatial resolution. This is an issue as we are specifically looking at the frontal cortex – a region that is often associated with higher brain functions. Indeed, the complex networking and data processing in the frontal cortex may only be observed using a high spatial resolution method. Additionally, the EEG montage was also not optimal for the spatial resolution. The data was collected with only sparse frontal channels, leaving many areas uncovered with any electrodes. As such, we are unable to obtain enough output from the electrodes to give us a comprehensive view of the frontal activity.

Moreover, the participants were not the most representative of the bilingual population. The data only samples participants from ages 18 to 30, with a low standard deviation of 3.2

years. The limited range of age produces only biased data, as a considerable amount of bilinguals was not represented in the data. Another concern with this sample is that, given their ages, the participants are likely to be mainly college students from the University of Macau, the institution where the study took place. This, again, suggests a biased population, as pursuing tertiary education is indicative of higher socioeconomic status. Also, some of the EEG data that we obtained from the original study was collected in a format that we were unable to process, reducing our sample size and potentially skewing our results even further.

Lastly, no statistical analyses were conducted as we are only basing our conclusions off of ERP data – it is unviable for us to perform these analyses within the time constraints we have. However, if time permits, ANOVA tests will be conducted to test for variance between the values extracted from the graphs above. This will allow us to definitely and statistically test for significance between groups.

Future works

As identified above, using EEG limited the spatial resolution of our data. Thus, we hope to implement the same experiment using fMRI, a neuroimaging procedure that provides higher spatial resolution, allowing us to look into the deeper structures of the brain. Additionally, the sample population can be improved. We can test a larger age group, and also collect data on other types of languages instead of only limiting ourselves to Chinese-English bilingual speakers. Lastly, this study could analyze other regions of the brain. For instance, due to the strokes that make up characters in Chinese, there could be activation in the visual cortex when processing Chinese characters, so analyzing the visual cortex could provide us with more significant findings.

Conclusion

This study examines the neurological processes that are activated when an individual is bilingual. The study also examined whether bilingual individuals show greater neural activation in their second language compared to their first. Contrary to expectations, the data revealed minimal differences in neural activation between languages, suggesting that the processes for learning both languages utilized similar neural resources. The data analysis suggested that semantic processing, being more complex, demanded more neural resources than morphological processing.

Currently, there are a lot of unanswered questions about how bilingual individuals can acquire various languages, and this study can help delve into the various processes that take place.

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