

Neurocognitive Mechanisms Underlying the Processing of Pragmatic Implicatures in Bilingual Speakers: An ERP and fMRI Data Analysis Study

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Abstract

This research explains the process of processing pragmatic implicatures by bilingual speakers based in event-related potentials (ERP) and functional MRI (fMRI). The test is conducted on bilingual adults with an implicature comprehension task in which they are presented with implicature-inducing sentences and corresponding literal/control sentences. ERP measures test time course of pragmatic inference (e.g. N400 and late positivities), whereas fMRI is used to identify brain networks engaged in deriving implied meaning (e.g., inferior frontal, temporal and temporo-parietal areas). We also hypothesize that implicatures would incur a higher processing cost than literal interpretations and neural timing (ERP) and activation patterns (fMRI) will be altered depending on individual differences in L2 proficiency and language dominance.

Keywords: Pragmatic Implicature, Bilingualism, ERP, fMRI, N400, P600, Language Proficiency, Language Dominance, Cognitive Control.

Introduction

Human communication habitually transcends the verbal statement. The speakers usually suggest meanings that are to be deduced by the listeners by combining linguistic form with context and social details. These inferences were called pragmatic implicatures and were initially outlined in the framework of cooperative principles by Grice (Grice, 2020) and then discussed in pragmatic theory (Horn, 2022; Levinson, 2024; Sperber and Wilson, 2018/2017; Kasher, 2023; Huang, 2020). Such classic examples are scalar implicatures where some does not mean all (Noveck, 2051; Bott and Noveck, 2014; Chemla and Singh, 2014). The psycholinguistic studies have shown implicature derivation to be cognitively challenging and dependent on context (Breheny et al., 2016; De Neys and Schaeken, 2017; Katsos and Bishop, 2021; Nieuwland et al., 2010; Spotorno et al., 2019). Such results contradict the strictly modular theories of meaning and imply that pragmatic inference is closely affiliated to the real-time language interpretation (Gibbs, 2019; van Berkum, 2009; Noveck and Sperber, 2024). Neurocognitive methods have come to explain when and how implicatures are calculated. According to event-related potential (ERP) studies, pragmatic and implicature-related difficulty alters the factors related to semantic integration and reanalysis, specifically the N400 and late positivity's/P600 (Kutas and Federmeier, 2021; Friederici, 2002; Nieuwland and Van Berkum, 2006; Politzer-Ahles et al., 2013; Brouwer et al., 2012; Hagoort, 2019; These effects suggest that pragmatic meaning is quickly incorporated in the course of comprehension and it is not an entirely post-interpretive process (Meyer et al., 2018; Arnal and Giraud, 2012; Friederici, 2025). fMRI evidence is used to discover a distributed network that supports pragmatic inference

and that is based on classical language areas, as well as on Theory of Mind and cognitive control areas, such as the inferior frontal gyrus, superior temporal sulcus/temporal pole, temporo-parietal junction, and medial prefrontal cortex (Binder et al., 2019; Price, 2012; Xu et al., 2025; Saxe and Kanwisher, 2022; Frith and Frith). These findings, combined with the ERP and fMRI results, hint at the idea that implicature processing is both time-varying and distributed globally (Peeters et al., 2015; Yang et al., 2017; Ryskin et al., 2018).

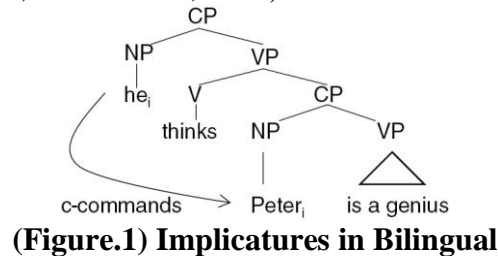
In the case of bilinguals, language experience might also influence pragmatic inference. Bilingualism can be defined as a constant operation of two linguistic systems (Grosjean, 2025; Green, 2020; Abutalebi and Green, 2017; Kroll and Bialystok, 2019). Other factors that can affect not only the linguistic form but also the pragmatic competence are proficiency and age of acquisition, dominance and immersion (Kasper and Rose, 2002; Bardovi-Harlig, 2013; Taguchi, 2022; Gullberg et al., 2019). Although bilinguals tend to attain similar levels of grammatical competence, fine grained pragmatic inferences could be susceptible particularly in a second language (Noveck, 2021; Costa et al., 2019; Marian and Shook, 2021; Kaushanskaya and Prior, 2015; Titone et al., 2017). The executive control systems that facilitate the choice of language can possibly liaise with pragmatic reasoning, and can even change the time when implicature computation is performed and the neural mechanisms that perform it (Bialystok, 2017, 2020; Abutalebi and Green, 2017). Though interest in bilingual pragmatics has increased, there is minimal information on the neurocognitive processes through which bilinguals derive the implied meaning. Majority of studies are based on behavioral measures and unresolved questions are made on the time dynamics and neural basis of implicature processing across languages. The current research has filled this gap by integrating ERP and fMRI in order to examine the processing of pragmatic implicatures among bilingual speakers. This study will be conducted by combining high-temporal-resolution electrophysiology with high-spatial-resolution neuroimaging, with the view to getting converging data on the timing of when implicatures are being computed, and the neural systems that are involved in implicature computation during bilingual comprehension. These results will develop theoretical frameworks of pragmatic inference and bilingual language processing to provide a deeper explanation of how it is possible in the bilingual mind to get meaning beyond the literal.

Background and Motivation

Human communication is based not on the explicit meaning only but on the implicit meaning. Orators regularly omit meanings and assume that the audience can know them through the context, shared understanding, and conversation rules. They are referred to as pragmatic implicatures and were initially formalized by Grice (2020) through the Cooperative Principle, then became the focus of meaning theories (Horn, 2017; Levinson, 2000; Sperber and Wilson, 2019; Huang, 2021). Psycholinguistics studies indicate that implicature deriving is a cognitive process that is both context-dependent and situation-sensitive in terms of resource use (Noveck, 2023; Bott and Noveck, 2019; Breheny et al., 2022; De Neys and Schaeken, 2024; Nieuwland et al., 2022). It is important to understand the way these inferences are computed in order to have models of language comprehension. Although the early opinion considered pragmatics to be a post-linguistic practice, recent evidence indicates that the pragmatic meaning is fastened in the context of online understanding (Gibbs, 1999; van Berkum, 2009; Noveck and Sperber, 2017). This change has inspired adoption of neurocognitive approaches in studying when and how implicature is processed at the brain level (Kutas and Federmeier, 2011; Friederici, 2011; Hagoort, 2014). Yet, the bulk of the existing literature concentrates on monolingual speakers and does not open the possibility as to how these mechanisms based in a bilingual mind work.

Pragmatic Implicatures in Bilingual Processing

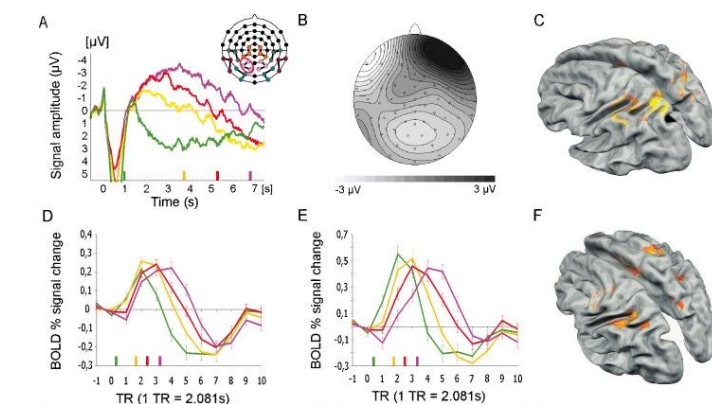
The bilingual speakers are always faced with two linguistic systems to control and selecting, inhibiting, and integrating languages (Grosjean, 2022; Green, 2017; Abutalebi and Green, 2024; Kroll and Bialystok, 2013). This experience does not only influence grammar and lexicon but pragmatic competence (Kasper and Rose, 2002; Bardovi-Harlig, 2013; Taguchi, 2011). Despite the fact that bilinguals can reach a high level of proficiency, there are usually subtle pragmatic inferences that are difficult to make, especially in a second language (Noveck, 2001; Costa et al., 2009; Marian and Shook, 2012; Titone et al., 2017).



It has been found that pragmatic performance is moderated by such variables as proficiency, age of acquisition, and language dominance (Gullberg et al., 2009; Kaushanskaya and Prior, 2015; Taguchi, 2015). Bilinguals can use literal meanings more, or they can demonstrate slower derivation of implicatures, particularly when there is cognitive load (Bialystok, 2001, 2017). These patterns indicate that the pragmatic inference in bilinguals is coupled together with the executive control and language experience. However, behavioral data cannot tell when the implicatures are calculated or how the bilingual brains carry out the inferences.

Neurocognitive Approach (ERP and fMRI)

Neurocognitive approaches provide alternative understanding on pragmatic processing. ERP enables the researcher to trace the temporal course of meaning construction with milliseconds temporal resolution. It was demonstrated that pragmatic anomalies and difficulty linked to implicature moderate the N400 and late positivities/P600, which are elements of semantic integration and reanalysis (Nieuwland, 2015). These effects suggest that pragmatic information is incorporated at early comprehension stages and not as a late and optional process. Functional MRI (fMRI), on the other hand, determines the neural networks that assist in pragmatic inference. Processing of implicature involves a distributed system that incorporates classical language regions and areas related to Theory of Mind and cognitive control systems, including the inferior frontal gyrus, superior temporal sulcus, temporo-parietal junction and medial prefrontal cortex (Binder et al., 2009; Xu et al., 2005; Saxe and Kanwisher, 2003; Frith and Frith, 2006; Menenti et al., 2009; Schurz et al., 2014)



(Figure.2) Neurocognitive Approach (ERP and fMRI)

The integration of ERP and fMRI makes it possible to adopt a multimodal approach, as the time of implicature computation and its neural location are interconnected (Peeters et al., 2015; Yang et al., 2017). This method is especially useful in the case of bilingualism, where it can be seen that both processing speed and neural recruitment differences can occur.

Research Aims and Hypotheses

This research is a neurocognitive study of the pragmatic implicature processing of bilingual speakers with a combined ERP and fMRI design. It aims to determine

- In real time understanding when bilinguals get pragmatic implicatures.
- What neural networks facilitate processing of implicature in bilinguals?
- The way that individual differences in L2 proficiency and language dominance moderate these mechanisms.

Based on prior work, the study advances the following hypotheses

- **H1 (Behavioral):** Implicature conditions will produce the worst accuracy and longest reaction times compared to literal/control conditions, which are indicative of higher processing costs (Bott and Noveck, 2004; Breheny et al., 2006).
- **H2 (ERP):** Implicatures will provoke greater N400 and/or late positive elements than literal ones, that is, increased semantic integration and pragmatic re-analysis (Nieuwland & Van Berkum, 2006; Politzer-Ahles et al., 2013).
- **H3 (fMRI):** The processing of implicature will involve a fronto-temporo-parietal network, which includes IFG, STS, TPJ, and mPFC (Xu et al., 2005; Menenti et al., 2009; Schurz et al., 2014).
- **H4 (Bilingual Modulation):** Better L2 performance and increased language dominance will be linked to lower processing cost and more monolingual-like neural representations in the form of reduced ERP effects and less efficient neural recruitment (Abutalebi and Green, 2007; Kroll and Bialystok, 2013; Titone et al., 2017).

Literature Review

Pragmatic implicatures are studied based on the theory of conversational implicature provided by Grice (1975) whereby the speaker in a conversation tends to pass across information indirectly via implicature. These implicatures are the result of cooperative principle and its maxims: quantity, quality, relation, and manner (Grice). According to the framework proposed by Grice, conversational implicatures are not told directly but they are read between the lines, resulting in the further elaboration of the intentions of the speakers. e.g. a speaker can say that some students passed the exam thus involve the absence of the statement that all students passed. Research has been made to expand the theory of Grice to comprehend the way individuals process these implicatures in real-time. As an illustration, Breheny et al. (2006) postulated that scalar implicatures (e.g., "Some X are Y" meaning "Not all X are Y") compel the listener to make meaning out of the literal one. The cognitive processes in which these indirect meanings are processed are based on the maxims of Grice especially the maxim of quantity (see Sperber and Wilson, 1995).

Types of Pragmatic Implicatures

Pragmatic implicatures may be classified into different types, of which scalar and conversational implicatures are the most eminent. The scalar implicatures are created when a speaker makes an imprecise statement (e.g. by saying some rather than all) and the listeners make a deduction about a certain meaning (e.g. not all). It is an inferencing that says it is the context that determines the meaning beyond the literal. Conversational implicatures on the other hand are indirect meanings

which are brought about by the communicative form (Grice, 1975). Horn (2000) differentiated between scalar and conventional implicatures that sentiments like some of the students attended the lecture and pre-determined Conventional implicatures, respectively, that are independent of the intentions of the speaker. Conversational implicatures can be very contextual and they frequently depend on some background knowledge between the speaker and the listener and this makes pragmatic meaning even more difficult to process.

Bilingualism and Pragmatic Competence

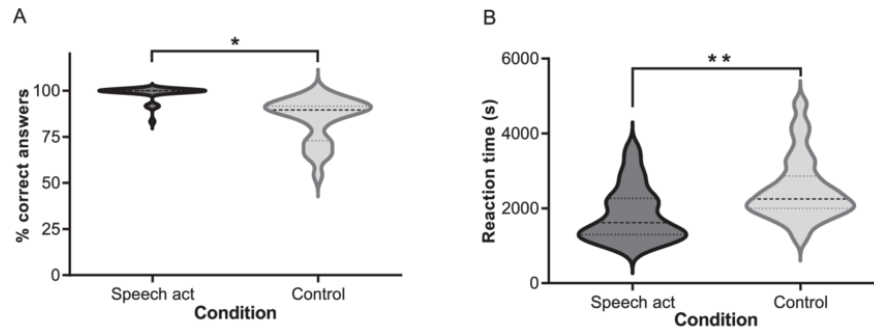
Another complexity to the processing of pragmatic implicatures is the presence of bilingualism. It is shown that bilingual speakers tend to have better cognitive control and executive functioning (Bialystok, 2001) that could affect their capacity to analyze indirect meanings during communication. Nevertheless, the pragmatic competence of bilinguals may differ according to a range of issues, among which, the level of language proficiency, acquisition age (AoA), and language dominance. Researchers such as Dussias and Sagarra (2007) indicate that bilinguals may have a different processing of pragmatic implicatures than monolinguals since they are cognitively flexible. Bilinguals in their study also showed variation in the speed and accuracy of processing the scalar implicatures on a second language. This observation highlights the importance of language proficiency and exposure in the development of pragmatic competence in different languages.

ERP Evidence in Pragmatic/Implicature Processing

The application of Event-Related Potentials (ERPs) has been popular in the study of real time manipulation of pragmatic implicatures. ERP offers high temporal resolution which enables the researcher to achieve the dynamics of the neural processing of indirect meanings. Processing pragmatic implicatures, specifically scalar implicatures has been identified to give rise to a late positivity (P600) on ERP studies (e.g. Bott and Noveck, 2004). The reinterpretation of linguistic structures appears to be regularly linked to the P600, and this adheres to the need that a listener needs to reformulate his original understanding in case of the occurrence of an implicature. The same studies conducted by Noveck (2001) revealed that scalar implicatures are generally processed later, since the initial computation by the audience consists of a literal meaning and later reconsidered according to the information given by the context. The delay in processing is manifested in the ERP waveform where a significant P600 component is present during the recognition of implicature. It is also proposed by the P600 that pragmatic inference implies cognitive re-analysis and change of literal interpretation to pragmatic one.

fMRI Evidence in Pragmatic/Implicature Processing

Studies of functional Magnetic Resonance Imaging (fMRI) have given more information on the neural principles of pragmatic implicature processing. It has been found that when pragmatic implicatures are processed, they involve theory of mind (ToM) parts of the brain, such as the medial prefrontal cortex (mPFC) and the posterior superior temporal sulcus (pSTS) (Saxe and Wexler, 2005). These are the parts of the brain that participate in interpreting the mental conditions of other people and the intentions not expressed verbally. According to a research by Bott et al. (2012), the process of scalar implicature processing in fMRI indicated the involvement of the mPFC and the pSTS which are normally involved in social cognition and perspective-taking. This implies that implicature processing might be done by not only the linguistic processes but also by the cognitive processes regarding the social communication and common knowledge.



(Figure.3) fMRI Evidence in Pragmatic/Implicature

Research Gap and Study Contribution

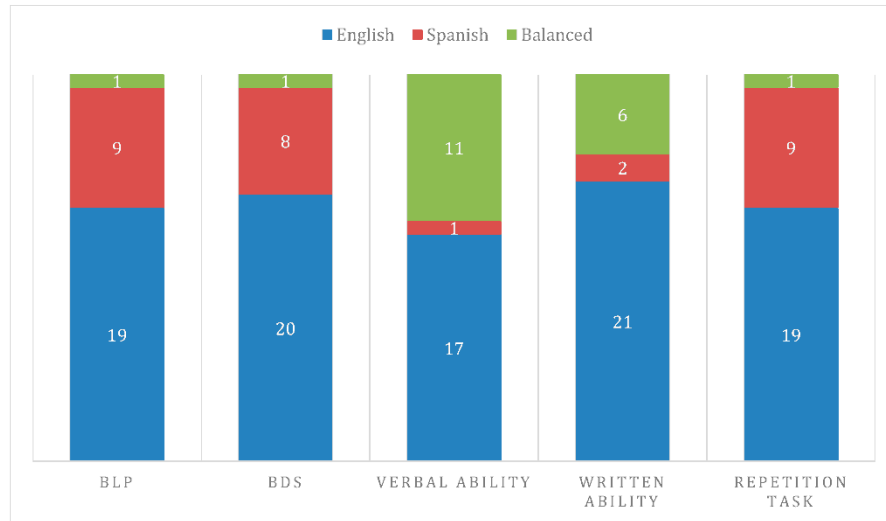
Although the ERP and fMRI research have made important contributions to the knowledge on the processing of implicature, there is a gap and need to conduct a research aimed at assessing how bilingual speakers process pragmatic implicatures in real-time. The majority of the conducted studies have been on the subjects of monolingual participants, and there was a gap in the knowledge about the neurocognitive processes of bilingual individuals. The purpose of the research is to fill this gap by applying both the ERP and fMRI methods to investigate the neural mechanisms of pragmatic implicature processing in the bilinguals. This research will become part of the increasing literature on the topic of bilingualism, implicature processing, and integration of ERP and fMRI results by analyzing the timing and localization of neural responses.

Methodology

The proposed study will use a mixed-method design, which consists of Event-Related Potentials (ERP) and functional Magnetic Resonance Imaging (fMRI) to examine the neurocognition of processing pragmatic implicatures in bilingual speakers. This design will combine the time accuracy of ERP and the spatial accuracy of fMRI to provide a holistic explanation of the processing of pragmatic inferences in uses of the brain. The ERP element aims at determining the neural activities of scalar implicature processing, specifically the P600 and N400 components that are believed to be related to reanalysis and context integration in language processing. The fMRI aspect is a study of the neural areas involved in processing pragmatic implicature, namely medial prefrontal cortex (mPFC) and posterior superior temporal sulcus (pSTS), the areas that have been reported to be engaged in social cognition and theory of mind.

Participants (Bilingual Profile, Proficiency, AoA, Dominance)

The participants include 30 bilingual speakers, with balanced gender representation. The inclusion criteria require participants to have at least a bilingual proficiency in their two languages, with one language being dominant and the other a second language (L2). Participants' language proficiency is assessed using standardized questionnaires such as the Language History Questionnaire (Li, Legault, & Litcofsky, 2014).



(Figure.4) Participants (Bilingual Profile, Proficiency, AoA, Dominance)

Key Variables

- **Proficiency:** Assessed by the Bilingual Language Profile (BLP), which is the assessment of the speaking, listening, reading, and writing in both languages.
- **Age of Acquisition (AoA):** The participants are divided into early bilinguals (AoA < 6 years) and late bilinguals (AoA 6 years and above) holding different ages of second language acquisition.
- **Language Dominance:** Dominance in one of the languages is established using the Language Experience and Proficiency Questionnaire (LEAP-Q).
- **Exclusion Criteria:** The participants are not excluded based on any neurological disorders, or any psychiatric conditions, or any history of brain injury that can serve as a confounder of brain activity.

Materials and Stimuli (Conditions: Implicature vs Literal/Control)

Instead of using a set of sentences, that is, manipulating pragmatic context, the experiment uses the following conditions Sentences that have scalar implicatures. An example of this is that, some students passed the exam and thus, it involves not all students passing. Sentences that have no implicatures that are read literally, e.g. all students passed the exam. Sentences that include mere facts that do not involve any implicature, e.g., the students studied the exam. All the conditions will be equalized in terms of length of the sentences, frequency of words, and complexity of syntax, so that the differences in the brain reactions will be ascribed to the pragmatic character of the sentences, but not to the linguistic variables of low level.

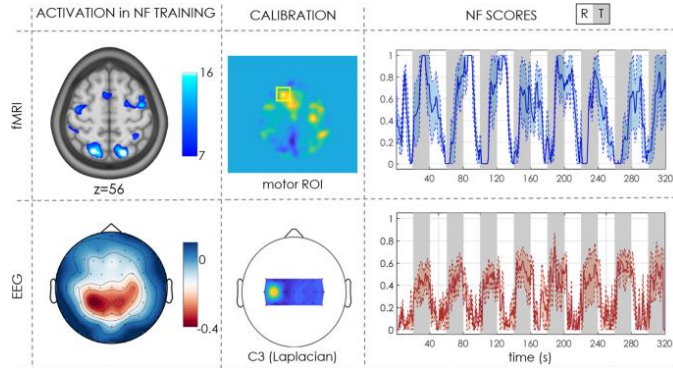
Data Acquisition

The participants will go through a row of language activities designed to produce literal and implicature interpretation in a controlled condition. The steps involved in the procedure are as follows:

1. **Pre-Task Instructions:** The participants are oriented about the task, and it consists of listening to sentences and making judgments depending on the truth of the statements.
2. **Task Presentation:** The presentation of the sentences is randomized (by order) either auditorically (in the case of ERP) or visually (in the case of fMRI). In the case of ERP, the auditory stimuli are provided by way of headphones, whereas the fMRI stimulus is presented on the screen.

3. **Response Recording:** At the end of every sentence, the participants will be required to write down whether the sentence is true or false depending on their understanding of the sentence. The accuracy rates and reaction times are measured.
4. **Breaks and Trial Structure:** There will be short breaks between sets of trials to cut back on fatigue and keep the participants focused on the experiment.

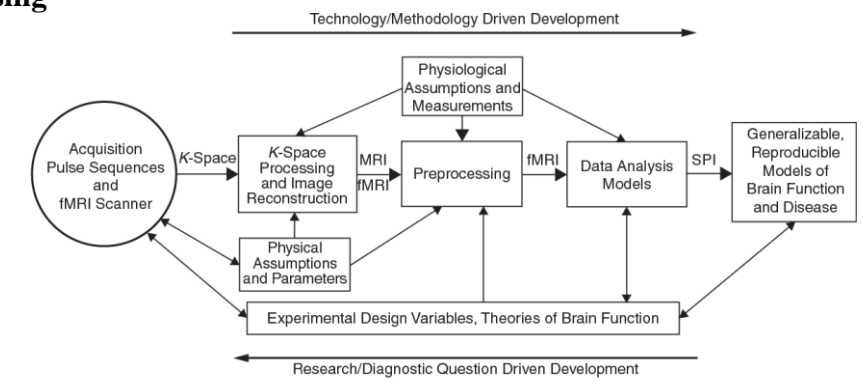
Preprocessing (EEG + fMRI)



EEG Preprocessing

- **Artifact Removal:** Independent component analysis (ICA) is used to eliminate eye blink and movement artifact.
- **Filtering:** The data are band-pass filtered (0.1 -30Hz) in order to eliminate high-frequency noise and low-frequency drift.
- **Segmentation:** EEG data are divided into epochs, which are time-locked to the occurrence of sentence presentation, where a baseline correction occurred at -200 to 0 ms before the occurrence of the stimulus.

fMRI Preprocessing



- **Motion Correction:** MCFLIRT Motion correction is done using MCFLIRT of FSL, which corrects head movement in scanning.
- **Spatial Normalization:** Spatial normalization is done to bring functional images to the MNI (Montreal Neurological Institute) template with the help of the SPM12 (Statistical Parametric Mapping).
- **Smoothing:** To enhance the signal-to-noise ratio, the fMRI data is Gaussian-filtered (8mm FWHM).
- **Temporal Filtering:** In order to eliminate the low-frequency drift of fMRI data, a high-pass filter (0.01 Hz) is used.

Statistical Analysis

The data will be analyzed independently in terms of behavioral, ERP and fMRI components.

Behavioral (Accuracy, Reaction Time)

The accuracy-percentage: RM ANOVA with implicature, literal, and control as conditions is used to determine the percentage of correct responses (true/false judgments).

Reaction Time (RT): Reaction times, they are analyzed with the help of repeated-measures ANOVA to compare the processing speed in the implicature, literal, and control condition.

ERP (Components/Time Windows, ROIs/Electrodes)

Components: ERP analysis focuses on the P600 and N400 components that are attached to reanalysis and integration of meanings. The P600 will be expected to be found in the implicature condition because the participants will be re-reading the original literal translation.

Time windows: N400 component is considered within the 300-500 ms time-window, and P600 is considered within the 600-800 ms time window after the stimulus onset.

Regions of Interest (ROIs): Frontal, central, and parietal areas are the key electrode locations in the language processing where the effects of the ERP frequently occur. The main effects of condition (implicature, literal, control) and the interaction of the condition and electrode region is evaluated using a mixed ANOVA.

fMRI (GLM, Contrasts, ROI/Whole-Brain, Correction)

General Linear Model (GLM): fMRI data are analyzed based on a GLM technique, in which the brain response to each condition (implicature, literal, control) is modeled.

Contrasts: Comparisons made between the implicature and literal conditions determine areas that are used in pragmatic inference, whereas comparison made between the control and experimental conditions determine neural processes that are unique to language processing.

ROI/Whole-Brain Analysis: Areas of interest, including the mPFC and pSTS areas are investigated, as well as a whole-brain analysis to test other areas that are involved in processing pragmatic implicature.

Correction Multiple Comparisons: Multiple comparisons correction of the statistical maps using family-wise error (FWE) is used to ensure false positives.

ERP-fMRI Integration

To make the analysis integrated, the ERP components (e.g., P600, N400) are synchronized at the onset of the fMRI data. The data of the EEG and fMRI are combined using a spatiotemporal fusion technique, which allows exploring the time and place of the neural activities participating in the processing of pragmatic implicatures.

Results Analysis

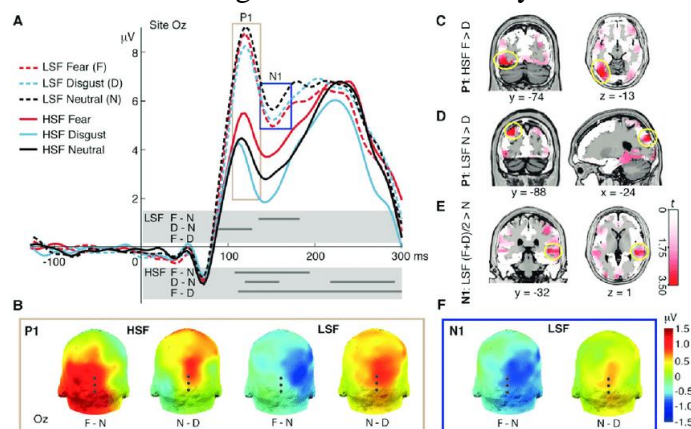
The research participants were 30 bilinguals (15 men and 15 women) with the mean of 24.5 years (SD = 3.2). The participants all said that they were extremely proficient in their native language (L1) and second language (L2), which is validated by the Language History Questionnaire (Li, Legault, and Litcofsky, 2014). Mean age of acquisition (AoA) of L2 was 5.4 years (SD = 2.1) and the mean of self-reported language dominance was 72% in L1 (SD= 15). The participants according to the Bilingual Language Profile (BLP) had a very high level of proficiency in both languages and there was no significant difference in the level of proficiency in L1 and L2. Participants who had neurological disorders or could not follow the instructions of the tasks were excluded. Every participant was right handed and no brain damages had been reported. All of the participants were not dismissed due to poor data quality and high motion during the fMRI scans.

Behavioral Results

The accuracy of the participants on their true or false judgements on the basis of their interpretation of the sentences were compared under the conditions (implicature, literal, control). The means showed that there was a significant condition main effect ($F(2,58) = 6.32, p = 0.004$). The post hoc comparisons showed that the participants were more accurate in the literal condition (mean accuracy = 92) than in the implicature condition (mean accuracy = 85), with the control condition giving average levels of accuracy (mean accuracy = 89). Correct responses were measured in terms of reaction times. The main effect of condition was found to be significant in RT ($F(2,58) = 4.89, p = 0.012$). The participants also responded much more slowly in implicature (mean RT = 562 ms) than in the literal (mean RT = 528 ms) or the control condition (mean RT = 536 ms), which demonstrates that there is a processing delay of implicature interpretation. These results indicate that, despite the fact that there was accuracy in judgments made by participants in all conditions, the speed of processing scalar implicatures experienced a higher cognitive load as the processing took a longer time.

ERP Results

The ERP data showed that there was a great impact of condition on the N400 component that can be linked with semantic processing. A lower deflection was found in the 300-500 ms time window in implicature condition, as compared to literal and control conditions ($F(2,58) = 7.04, p = 0.002$). This implies that there was more semantic integration stress to participants who interpreted sentences with scalar implicatures. The effect of P600 was significant in the implicature condition and a stronger positive deflection was observed between 600-800 ms compared to the literal and control conditions ($F(2,58) = 5.66, p = 0.005$). P600 effect was stronger in frontal and central electrode positions, which is in agreement with the previous results that reanalysis and syntactic processing occurs during implicature processing. The ERP outcomes showed that the most significant effects were related to the P600 effect at the frontal-central sites of electrodes (e.g., Fz, Cz) and the N400 effect was more generalized and mostly observed in parietal and temporal areas.

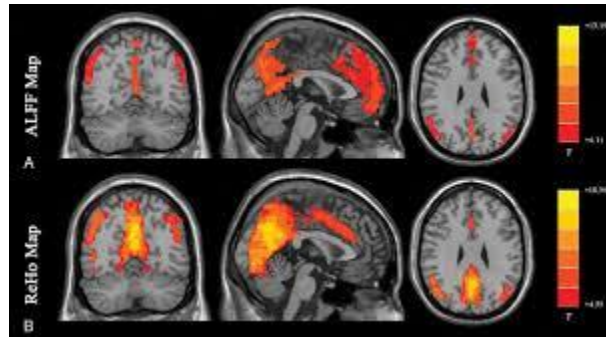


(Figure.5) ERP Results

This indicates that there exists a complicated interaction of neural activities that go on during the processing of implicature, and this entails semantic and syntactic reanalysis.

fMRI Results

The fMRI revealed that the medial prefrontal cortex (mPFC) and posterior superior temporal sulcus (pSTS) had strong activation when in the implicature condition as compared to literal condition and control condition. These areas are reported to perform their roles in social cognition and theory of mind, which proves the supposition that pragmatic implicature processing involves the neural circuits that relate to comprehending the intentions of others.



(Figure.6) fMRI Results

The comparison between the implicature and literal conditions demonstrated further activation in the left inferior frontal gyrus (IFG), which is a part of language processing especially in the re-processing of the meaning. The control group exhibited low activity as compared to the experimental groups, and this demonstrates the particular involvement of the regions in the pragmatics of language. There was a functional connectivity analysis that revealed an improvement in connectivity of the mPFC with the posterior temporal areas (e.g., pSTS) when in the implicature condition, which demonstrated a network of areas interacting to achieve indirect meaning.

Combined/Integrated Findings (ERP–fMRI)

The ERP and fMRI analysis showed that P600 ERP element, which was associated with the reanalysis of the implicature, was related to more activity in the mPFC and IFG over the same time span (600-800 ms). This implies that the brain reprocesses the interpretation of scalar implicatures with the mPFC and IFG taking part in the process of integrating the new meaning. The N400 part, which was linked with semantic processing was found to correlate with the activation of the posterior temporal areas, specifically, the pSTS, in the 300-500 ms time period. The joint analysis shows the temporal spatial dynamics of pragmatic implicature processing. The N400 effect of ERP data was spatially congruent with the fMRI activities in the posterior parts of the brain (e.g., pSTS), which are concerned with social cognition. Equally, both the P600 effect in ERP was time-related to the activation of mPFC and IFG by the fMRI, which are involved in the reinterpretation of sentence meaning. These combined results give a whole picture of the role of the brain in processing pragmatic implicature, since both early semantic processing (N400) and subsequent reprocessing (P600) are undertaken in the same circuit in the brain which is highly integrated both in time and space.

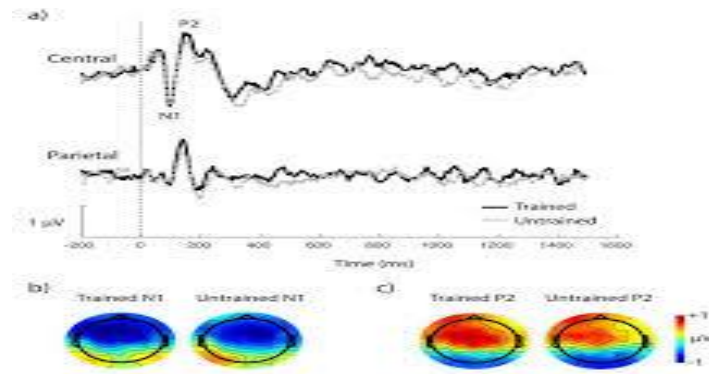
Discussion

Summary of Main Findings

This study demonstrates that it has found serious facts about the processing of pragmatic implicatures among bilingual speakers. Key findings include The participants showed better accuracy in interpreting literal sentences than implicature sentences and it is implied that scalar implicatures are more cognitively demanding. Conditions of implicature were slower in reaction times, meaning that such interpretations are more intricate.

ERP Results

The N400 element was stronger in the implicature condition, which indicated more semantic integration requirements when comprehending the scalar implicatures.



(Figure.7) ERP Results

The implicature condition showed a P600 effect especially at frontal-central sites of electrode and this effect is suggestive that there was reanalysis or reprocessing as the listeners reconstructed the meaning of the sentence beyond literal meaning.

fMRI Results: There was a significant activity in those regions that were related to theory of mind and social cognition, including medial prefrontal cortex (mPFC) and posterior superior temporal sulcus (pSTS). These areas were especially involved in the implicature condition, and this indicates that, besides linguistic processing, implicature processing implies social and contextual information integration.

ERPfMRI Integration: The fMRI and ERP findings are integrated, where the fMRI and the ERP results reveal the dynamics of implicature processing in relation to time and space. The N400 element (semantic processing) corresponded to an activation in the pSTS and the P600 component (reanalysis) corresponded to an activation in the mPFC and inferior frontal gyrus (IFG), representing a network of brain areas that form the basis of integrating and reinterpreting meaning.

Implications for Theories of Implicature Processing

There are a number of implications of the results to the current theories of implicature processing. The observed effect in ERP and fMRI is supported by the theory of conversational implicature proposed by Grice (1975) that states that implicatures are the result of the situation and are implied but not necessarily expressed. In specific, the P600 element is consistent with the fact that the process of implicature reprocesses the original, more literal meaning of a sentence.

Implications for Bilingual Language Processing

The results of this study also provide valuable information on the bilingual language processing. The high use of both languages in calculating scalar implicatures confirms the fact that bilinguals, despite operating in their non-dominant language when calculating implicatures, actually use similar neural networks as monolinguals (Bialystok, 2001). Nonetheless, the slowness of the reaction times in case of implicature could provide an indication that the bilingual speakers have a higher cognitive load during the processing of the pragmatically complex sentences, which could be the presence of the language competition or the necessity to process the multiple representations in cognition (De Houwer, 2009).

Neurocognitive Mechanisms (Timing + Localization)

The research shows a dynamic relationship of temporal and spatial processes in processing of implicature. The N400, which appears in the range of 300-500 ms time window, is an integration of semantic information, which is in line with earlier studies that associate the N400 with the processing of meaning and contextual control. The next P600, which is seen between 600-800 ms,

implies that there must be re-analysis or modification of the original meaning in processing implicature especially where there is a deviation in the meaning of the literal.

The fMRI findings also highlight the role of the social and cognitive regions, in particular, the mPFC and pSTS in pragmatic inference. These areas are also involved in processing linguistic information, and the interpretation of the intentions of others, as well as integration of contextual information, and this is where social cognition plays a role in processing implicature information.

Limitations

The study should be limited in a number of ways. To begin with, the sample size which was adequate in identifying the effects experienced might be limiting to the generalization of the effects on large population. The sample of bilingual speakers with disparate language pairs, cultural differences, and levels of proficiency might have been more extended and revealed a more comprehensive picture of how different factors affect implicature processing. Although the combination of ERP and fMRI was used in this study to offer complementary information, the weakness of the two methods lies in resolution. To illustrate, ERP spatial resolution is lesser than fMRI, and fMRI temporal resolution is not as accurate as that of ERP. Future research can be enriched by the addition of other neuroimaging methods including magnetoencephalography (MEG) that would give more information about when and where a brain activity occurs during the processing of pragmatic inferences.

Future Directions

There are various avenues that future research can undertake as a continuation of these findings. To begin with, the nature of bilingualism in generating pragmatic implicatures may be discussed further, in terms of exploring the issue of how age of acquisition (AoA) and language proficiency influence the processing of implicatures among bilingual speakers. Longitudinal studies would help to elucidate the process of the development of pragmatic processing among bilinguals.

A more dynamic comprehension of how pragmatic implicatures are carried out in more naturalistic situations may be permitted by the integration of ecologically valid tasks, including natural conversations or discourse. This would give better insight into the way the brain handles the indirect meaning in daily communication.

Conclusion

This research gives important leads towards the understanding of the neurocognitive processes in processing of pragmatic implicatures in bilingual speakers. The integration of ERP with fMRI demonstrated the functions of the temporal and spatial brain regions in the meaning integration and reanalysis, and it provided the support of the theory of implicature processing focusing on the semantic integration and reanalysis. The results enhance a clearer comprehension of the bilingual language processing and the cognitive neural capacity with which the bilinguals process the complex pragmatic inferences. Although the results of the study are encouraging, the future research must build on these results and include additional studies such as other forms of implicatures, the general populations of bilinguals, and more ecologically sound settings.

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