AN fMRI STUDY OF RELATIVE CLAUSE IN COMPREHENSION AMONG NATIVE AND NON-NATIVE MALAY LANGUAGE SPEAKER

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2021

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by

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Research project report submitted in fulfilment of the requirements for the Master of Cognitive Neurosciences

August 2021

ACKNOWLEDGMENT

First and foremost, I would like to thank Allah the almighty for easing my Master of Cognitive Neuroscience journey.

I want to express my highest gratitude to the supervisory team, Dr Jong Hui Ying and Dr Aini Ismafairus Abd Hamid, for their continuous guidance and encouragement. Not to forget, Professor Dato' Dr Jafri Malin Abdullah for his insight.

My deepest gratitude to Mr Hazim for his help in the fMRI paradigm development. Thanks to the Science Officer and Radiographers who helped me during the data collection process. Very much thanks to Jabatan Radiologi, HUSM, for allowing me and my friends to use their facility.

This project would not be completed without the help from the members of the fMRI research group: Sabrina, Maisarah, and Syazwani, for their assistance in the data collection process and data analysis. Their assistances were meaningful for me, especially during this Covid-19 pandemic time.

I am extremely grateful to have supportive parents alongside this journey. Their prayers and blessing beyond imagination.

Thanks to everyone who is, directly and indirectly, involved in this research project.

I also would like to acknowledge the Master of Cognitive Neurosciences program for the research grant (BENCH FEE PROGRAM SARJANA NEUROSAINS KOGNITIF (IPS@KL) - 401/PPSP/E3170003) to fund this research project. Thank you.

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σ_W	Intra-subject variability
σ_B	Inter-subject variability
μ_D	Population mean
α	Alpha
n	Timepoint per condition
η^2	Eta squared

LIST OF ABBREVIATIONS

EEG	Electroencephalogram
ERP	Event Related Potential
fMRI	functional Magnetic Resonance Imaging
MRI	Magnetic Resonance Imaging
SRC	Subject relative clause
ORC	Object relative clause
SVO	Subject-verb-object
L1	Native speaker
L2	Non-native speaker
NP	Noun phrase
VP	Verb phrase
BA	Brodmann Area
ROI	Region of interest
BOLD	Blood oxygenation level dependent
DLT	Dependency locality theory
IEC	Institution Ethics Committee
EPI	Echo Planar Imaging
TR	Repetition time
TE	Echo time
L	Left
R	Right
RFX	Random-effect analysis
FFX	Fixed-effect analysis

ANOVA	Analysis of Variance
SD	Standard deviation
KRS	Klausa relatif subjek
KRO	Klausa relatif objek
SKO	Subject-kata kerja-objek
IFG	Inferior frontal gyrus
LIFG	Left inferior frontal gyrus
pIFG	Posterior inferior frontal gyrus
TL	Temporal lobe
AG	Angular gyrus
STG	Superior temporal gyrus
LSTG	Left superior temporal gyrus
aSTG	Anterior superior temporal gyrus
pSTG	Posterior superior temporal gyrus
MTG	Middle temporal gyrus
SPL	Superior parietal lobule
SMG	Supramarginal gyrus; MTG
PoG	Postcentral gyrus
PrG	Precentral gyrus
OFuG	Occipital fusiform gyrus
MCgG	Middle cingulate gyrus
MSFG	Superior frontal gyrus medial segment
SFG	Superior frontal gyrus
MOG	Middle occipital gyrus
IOG	Inferior frontal gyrus

FuG	Fusiform gyrus
PCu	Precuneus
WFA	Word form area

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KAJIAN fMRI MENGENAI PEMAHAMAN KLAUSA RELATIF DALAM KALANGAN PENUTUR NATIF DAN BUKAN NATIF BAHASA MELAYU

ABSTRAK

Pendahuluan: Pemahaman ayat adalah suatu proses kognitif yang mencabar. Pemahaman ayat kompleks dan tidak kanonikal seperti klausa relatif boleh menyebabkan pengaktifan kawasan otak tertentu.

Objektif: Kajian ini menyiasat sama ada terdapat pengaktifan saraf berfungsi di kawasan otak frontal dan temporal semasa proses memahami klausa relatif bahasa Melayu. Kajian ini juga bertujuan untuk mencari perbezaan kawasan pegaktifan otak di antara penutur natif (L1) dan penutur bukan natif (L2) bahasa Melayu.

Metodologi: Kajian pengamatan ini telah dijalankan di Hospital USM Kubang Kerian, Kelantan dari bulan disember 2020 sehingga bulan April 2021 melibatkan empat orang penutur natif (min umur = 24.2 tahun, sisihan piawai = 1.25) dan empat orang penutur bukan natif (min umur = 23.5 tahun, sisihan piawai = 0.43) Bahasa Melayu. Klausa relatif subjek (KRS), klausa relatif objek (KRO) dan subjek-kata kerja-objek (SKO) Bahasa Melayu telah digunakan sebagai bahan kajian. Para peserta kajian telah diminta untuk melakukan tugasan penyesuaian ayat-gambar ketika pengukuran fMRI dijalankan.

Keputusan: Pengaktifan saraf berfungsi di kawasan otak dalam kalangan penutur natif dan bukan natif telah diteliti dan dibandingkan. Analisis kesan-rawak (RFX) telah dijalankan ke atas data fMRI menggunakan analisis ANOVA dua hala pengukuran berulang. Analisis kesan utama kepada kumpulan pada ambang nilai $p_{uncorrected} < 0.001$, saiz kluster > 20 voksel telah mendapati pemahaman klausa relatif Bahasa Melayu telah mengaktifkan saraf berfungsi di kawasan otak frontal dan temporal bagi penutur natif dan bukan natif. Analisis bandingan pelbagai bagi L1>L2 telah menunjukkan perbezaan signfikan yang ketara pada sisi kiri bahagian otak temporal-parietal. Manakala, untuk L2>L1, pengaktifan yang signifikan tersebar pada sisi kanan bahagian otak frontal, temporal, parietal, dan oksipital. Sebagai tambahan, analisis ANOVA sehala pengukuran berulang, bagi masa tindak balas kumpulan penutur natif mendapati tiada perbezaan signifikan antara KRS, KRO, dan SKO ($F(2,82) = 2.43$, nilai $p = 0.094$, $\eta^2 = 0.056$). Sementara itu, analisis ANOVA sehala pengukuran berulang, kepada masa tindak balas kumpulan penutur bukan natif, ($F(2,54) = 3.13$, nilai $p = 0.052$, $\eta^2 = 0.104$) juga menunjukkan tiada perbezaan signifikan pada masa tindak balas antara kondisi KRS, KRO, dan SKO.

Kesimpulan: Hasil dapatan daripada kajian ini mencadangkan bahawa pemahaman klausa relatif Bahasa Melayu telah mengaktifan saraf berfungsi di kawasan otak yang berbeza dalam kalangan penutur natif dan bukan natif. Kajian ini juga menunjukkan kedua-dua kumpulan penutur natif dan bukan natif lebih mudah memahami KRS berbanding KRO. Hasil dapatan daripada kajian ini boleh diaplikasikan dalam intervensi bahasa klinikal. Ia juga dijangka akan memberi manfaat bagi kanak-kanak dan orang dewasa yang mempunyai masalah kecelaruan bahasa.

Kata kunci: klausa relatif, pemahaman ayat, pengaktifan saraf berfungsi, fMRI, pengimejan neuro, otak, penutur natif, penutur bukan natif

AN fMRI STUDY OF RELATIVE CLAUSE IN COMPREHENSION AMONG NATIVE AND NON-NATIVE MALAY LANGUAGE SPEAKERS

ABSTRACT

Introduction: Sentence comprehension is a cognitively demanding process. The comprehension of complex and non-canonical sentences like relative clauses caused the activation of particular brain regions.

Objectives: This study investigated whether there is functional neural activation at the frontal and temporal brain regions during the comprehension of the Malay relative clause. This study also aimed to find the differences in the activated areas among the native (L1) and non-native (L2) Malay language speakers.

Methodology: This observational study was conducted at the Hospital USM Kubang Kerian, Kelantan, from December 2020 to April 2021, involving native (L1) and non-native (L2) Malay language speakers. Four L1 (mean age = 24.2 year old, SD = 1.25) and four L2 (mean age = 23.5 year old, SD = 0.43) participated in this study. The subject relative clause (SRC), object relative clause (ORC) dan subject-verb-object (SVO) were used as study stimuli. They were asked to do a sentence-picture matching task during fMRI measurement.

Results: The functional brain activation of L1 and L2 were observed and compared. The random-effect analysis (RFX) using two-way repeated measure ANOVA was conducted for the fMRI data. The main effect of the group at the $p_{\text{uncorrected}} < 0.001$, cluster size > 20 voxels found that the comprehension of Malay relative clauses had activated frontal and temporal brain regions in L1 and L2. The multiple comparisons of L1>L2 showed a significant difference left-lateralised in the temporo-parietal region.

While for L2>L1, the significant activations were indicated distributed to the frontal, temporal, parietal, and occipital regions that lateralised to the right hemisphere. Additionally, one-way repeated measure ANOVA of reaction time in the L1 group showed no significant difference between SRC, SVO, and ORC ($F(2,82) = 2.43$, $p = 0.094$, $\eta^2 = 0.056$). Meanwhile, the one-way repeated measure ANOVA of reaction time in the L2 group showed no significant difference between conditions SRC, ORC, and SVO ($F(2,54) = 3.13$, $p = 0.052$, $\eta^2 = 0.104$).

Conclusion: The findings suggested that comprehension of Malay relative clauses had caused the activation at different brain regions amongst its L1 and L2. It was also found that both L1 and L2 groups showed their preference in SRC over ORC. The findings from this study can also be applied in clinical language intervention, and it is expected to benefit children and adults with speech and language disorders.

Keywords: relative clause, sentence comprehension, functional neural activation, fMRI, neuroimaging, brain, native speaker, non-native speaker

CHAPTER 1

INTRODUCTION

1.1 Study background

Reading a book, listening to stories or lectures, and answering questions are the example of everyday activities requiring sentence comprehension. The ability to comprehend the sentences from those resources enables us to respond to the messages delivered. On the contrary, when a person failed to understand the sentence, it will cause them to miss critical information, and eventually, communication break down. A person who has agrammatism, like aphasic, is an example of a person who has difficulty understanding the sentence (Aziz et al., 2020).

Sentence comprehension is a process involving interpreting strings of information or the meaning of each word in the sentence sensibly. From the linguistic view, three phases are involved in understanding a sentence. It begin with syntactic and lexical parsing, assigning thematic roles, and finally, building the conceptual representation of the sentence (Arantzeta et al., 2017; Friederici, 2011).

Not only that, sentence comprehension is a sophisticated process that required multiple brain regions to served the operation. This phenomenon has fascinated many researchers to study the sentence comprehension process in the brain (Meltzer et al., 2010; Özge et al., 2020; Rodd et al., 2015). They have used various neuroimaging modalities such as the electroencephalogram (EEG)/ event-related potential (ERP) (Bulut et al., 2018; Harding et al., 2019; Xiong et al., 2019), eye tracking (Chan et al., 2018; K. Xu et al., 2020a; Yang and He, 2020) and functional magnetic resonance imaging (fMRI) (Lee et al., 2016; Xu and Duann, 2020) to examine the neural substrate underlying the sentence comprehension process. From those neuroimaging techniques, the researchers have found the involvement of the frontal and temporal brain regions in sentence comprehension (Bulut et al., 2018; K. Xu et al., 2020b).

The relative clause was often used as the research stimulus to observe the neuronal activation related to sentence comprehension. In the relative clause, the order of arguments does not follow the subject-verb-object. Thus, a relative clause is a non-canonical sentence in which the sequence of its syntactical structures deviated from the usual word order. Hence, it is known that in a relative clause, the theme precedes the agent, which makes the sentence more complex and difficult to process (Adamou, 2017; Krebs et al., 2018; Özge et al., 2020)

The Malay relative clause marked with the syntactic structure *yang*, which is embedded in the noun phrase. Acquisition of Malay relative clause started as early as preschool age with the inclination to subject relative clause (SRC) (Bakar et al., 2016). However, there was no research conducted on Malay relative clauses using any neuroimaging modality. Therefore, we do not know the neural substrate involved in the comprehension process of the Malay relative clause, especially among its native (L1) and non-native (L2) speakers.

1.2 Definition of concept

1.2.1 Language

Language is a complex communication system that encompasses sounds, words, symbols, and grammar used by a group of people in a region. Linguists have identified five domains of language involving phonology, morphology, semantic, syntax, and pragmatic. Phonology studied the sound system of that particular language, while morphology concerned with forms and the formation of word in a language. Phonology, morphology, and syntax formed the structure of the language. Semantic gave meaning to language, while pragmatic described how the language is used in a sensible social context. Figure 1.1 explained the components of language.

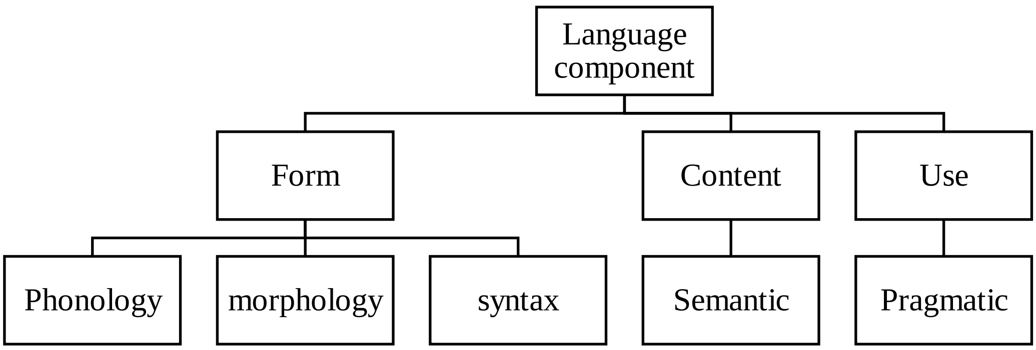

Figure 1.1: The language components

Syntax was the primary focus of the present study. Syntax determined the principles of sentence construction (Karim et al., 2015; Matchin and Hickok, 2020) in a particular language. Syntax governed the grammatical structure and rules that combine words into phrases and, eventually, a sentence (Grodzinsky and Friederici, 2006; Karim et al., 2015). One should understand the element of the sentence structure before they could produce the grammatical output.

Every sentence contained a sequence of words known as element or constituent (Karim et al., 2015). According to a language's syntactic rules, all constituents should be arranged to form a phrase and then a sentence. For example, the sentence (see figure 1.2) has three constituents.

	Constituent number	Type of phrase
The grandfather	1	Noun phrase (NP)
chase	2	Verb phrase (VP)
the boy	3	

Sentence: [The grandfather] [chase the boy]

NP VP

Figure 1.2: The constituent and phrases of the sentence 'The grandfather chase the boy'

In this particular sentence, constituent (1) makes the noun phrase (NP), while constituent (2) and (3) are combined to construct the verb phrase (VP). The NP and VP were sequenced to form a sentence, 'The grandfather chase the boy'.

1.2.2 Relative clause

Usually, the words in a sentence are arranged in the canonical subject-verb-object (SVO) word order. Nonetheless, the arrangement of words in relative clauses deviated from a syntactic rule of the language or embedded with another syntactical structure in the head of NP (Karim et al., 2015). There are two types of relative clauses: subject relative clause (SRC) and object relative clause (ORC). Although the ORC and SRC were different in terms of word order to present the various relations between the verb and its argument (Xu et al., 2020), it still gave the same meaning in the premise of who doing what to whom, but differed pragmatically.

Sentence comprehension began from building the syntactic structure based on the lexical category, parsing to determine the thematic roles of 'who is doing what to whom' based on the lexical and structural information, and finally integrating pieces of information in the sentence to give meaning to the sentence (Friederici, 2011).

Prior research suggested sentence comprehension, especially relative clauses, occurred in the brain at the inferior frontal gyrus (IFG) and temporal lobe (TL) (Just et al., 2009; Lee et al., 2016). The study of relative clauses in Chinese (Xu et al., 2020a, 2020b), Cantonese (Chan et al., 2018), and English (Chen et al., 2006) also supported those frontal and temporal brain regions as the core processing area in comprehending a relative clause.

1.2.3 Native speaker (L1) and non-native speaker (L2)

It was estimated 300 million Malay language speakers globally (Ku Hasnita et al., 2013). The majority of Malay language speakers originated from the South-East Asia region, such as Malaysia, Singapore, Brunei, and Indonesia. In Malaysia, the Malay language is not only spoken by the Malay. In fact, it is also utter by other races such as Chinese and Indian. Generally, in Malaysia, Malay is often considered as the native speaker of the Malay language (L1), while Chinese, Indian, and the other races are the non-native Malay language speakers (L2).

The native (L1) and the non-native (L2) speakers of the language can be differentiated based on the time they acquired the language (Bentz et al., 2015). The native speaker of the language (L1) is the person who acquired the language as their first language in childhood (Scharenborg and Van Os, 2019). They are regarded as proficient users of the language (Cook, 1999) and have better lexical diversity than L2 (Bentz et al., 2015).

Contrary to L1, non-native (L2) speaker of the language is portrayed as people who learned the language as a second or third language (Cook, 1999) and acquired it later than L1. The L2 would never become L1 despite the long-life training, although eventually, they become proficient language users. The L2 is expected to have lower lexical diversities (Bentz et al., 2015) and lower language processing ability than L1 (Lev-Ari, 2014; Scharenborg and van Os, 2019).

The differences in L1 and L2 language abilities have attracted the researcher to learn about their sentence processing using a relative clause. Therefore, a neuroimaging modality like fMRI is the best to examine the functional neural activation during the sentence comprehension of the Malay language.

1.3 Problem statement

The failure to identify the functional brain region related to the Malay relative clause was due to insufficient research on this topic. Before this research was conducted, we usually associate the Malay relative clause's comprehension process, including its neural basis, with English because of the similarity in the SVO word order. Albeit that was a credible argument, the researcher is confident that more research is needed to prove it.

Hence, it inspired the researcher to study the comprehension of the Malay relative clause using fMRI to map the fundamental neural substrate. This research will also include the L1 and L2 of Malay language speakers to see the differences in processing the Malay relative clause. The findings could give us a deeper understanding of how the Malay relative clause is processed, which later can be applied in the clinical and linguistic field.

1.4 Study rationales

The researcher aspired to conduct a study on the Malay relative clause's comprehension to map the Malay language's functional neural activation. The researcher also wished to examine the differences in the sentence comprehension process among L1 and L2 and the role of working memory in sentence comprehension.

1.4.1 Mapping functional neural activation during sentence comprehension of the Malay relative clause

Numerous past studies focused on activation of the frontal and temporal region during sentence processing (Golestani et al., 2006; Hsu et al., 2017; Xu et al., 2020). The activation areas are predominantly in the left hemisphere (Vigneau et al., 2006; K. Xu et al., 2020b).

A recent study found that sentence comprehension not only involved Wernicke's (BA 21 and 22) and Broca's area (BA 44 and 45) (Peelle, 2017; Tomasi and Volkow, 2020). The advancement in neuroimaging techniques revealed the other area, such as the parietal lobe, hippocampus, and occipital lobe, also activated depending on who and how linguistic information is presented.

To date, only one study conducted on the Malay language relative clause. Bakar et al. (2016) studied the acquisition of Malay relative clauses among preschool children. Unfortunately, no neuroimaging modality was used in that research to understand the functional neural activation of pre-schoolers. Thus, we cannot confirm whether the Malay language's functional neural activation at the frontal and temporal brain regions.

1.4.2 Sentence comprehension of L1 And L2

The sentence comprehension of L1 and L2 could be distinct. Consistent with past studies, L2 is said to have lower sentence comprehension ability than L1 (Kim et al., 2017; Lev-Ari, 2014; Pliatsikas et al., 2017). A meta-analysis study by Sulpizio et al. (2020) supported this statement when discovered different neural activation during sentence comprehension among L1 and L2.

Few factors contributed to the disparity, for instance, the age of acquisition of either they were early or late bilingual (Golestani et al., 2006), limitation in lexical diversity (Bentz et al., 2015), speaker's competency in using the language (Golestani et al., 2006), amount of language exposure, manner of acquisition, linguistic distance, modality of acquisition and frequency of language switching (Połczyńska et al., 2017). Those circumstances influenced the tunes of neural plasticity in the brain, which then shaped the language processing ability in L2 (M. Chen et al., 2020).

Since the present research examined the sentence processing ability among L1 and L2 of the Malay language, it is exciting to see whether the result will be consistent with the past studies.

1.4.3 Working memory in sentence comprehension

The relative clause was often used to manipulate the syntactic complexity by attaching a syntactic element in the NP's head of a particular sentence. The attachment modified the element in the sentence, turning the sentence into non-canonical (Harding et al., 2019). The deviation from the rule made the structure more complex (Xiong et al., 2019). A complex sentence is difficult to process and comprehend because it need a higher cognitive load (Mansbridge et al., 2017).

For these reasons, working memory is required to store the information of the syntactic structures that have been processed. Again, working memory resources are also needed to integrate the information in the sentence (Andrews et al., 2006). Prior research has acknowledged that ORC is more difficult to comprehend in language that has SVO word order due to its syntactic complexity, which also consumed higher working memory resources than SRC (Andrews et al., 2006; Vogelzang et al., 2020).

1.4.4 Clinical applications

There was plenty of research using relative clauses as their stimuli. For example, it was used to understand the properties of language impairment in aphasia (Friedmann, 2008). Furthermore, Liu et al. (2019) predicted the cognitive aging in adults from the changes in their receptive language skills. In addition, Frizelle and Fletcher (2014) also employed relative clauses to profile the syntactic ability in children with specific language impairment.

Hopefully, this research will enable us to map the syntactic processing of the Malay language relative clause in the cortices. Hence, later the finding will allow us to understand the typical syntax development of children of Malay language speakers, study the properties of sentence structures after brain injury and in the aphasic patient, as well as predict language comprehension in the cognitive aging of Malay language speaker.

Given these reasons and the research gaps found in the literature, the researcher is convinced to investigate syntactic processing and comprehension among L1 and L2 of Malay language speakers.

1.5 Research Question

What are the functional neural activation of the subject relative clause (SRC), object relative clause (ORC), and subject-verb-object (SVO) among native (L1) and non-native (L2) Malay language speakers?

1.6 Objectives

General:

To propose the cortical syntactical processing map of the comprehension of the Subject relative clause (SRC), Object relative clause (ORC), and Subject-Verb-Object (SVO) of native (L1) and non-native (L2) Malay language speakers

Specific:

(1) To identify the functional neural activation of the Malay syntax of native (L1) and non-native (L2) Malay language speakers.

(2) To compare the functional neural activation of the Malay syntax between native (L1) and non-native (L2) Malay language speakers.

1.7 Hypothesis

Hypothesis 1

H_a: The functional neural activation of Malay language syntax is at the frontal and temporal region for native (L1) and non-native (L2) Malay language speakers

H_0: There is no functional neural activation of Malay language syntax at the frontal and temporal region for native (L1) and non-native (L2) Malay language speakers.

Hypothesis 2

H_a: The functional neural activation of Malay language syntax is different among native (L1) and non-native (L2) Malay language speakers.

H_0: There are no differences between functional neural activation of Malay language syntax among native (L1) and non-native (L2) Malay language speakers.

1.8 Summary

This chapter had discussed the research background, the definition of the concept, the problem statement, and rationales on why the research must be conducted. This chapter also proposed the research objectives and the hypothesis. The next chapter will review the past literature and present the conceptual framework for the present study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviewed the past literature related to sentence comprehension of relative clauses, started from neuroanatomy of language, the Malay relative clause, the theory that explained the comprehension process of a relative clause to the conceptual framework of relative clause comprehension.

2.2 Neuroanatomy of language

Friederici (2011) stated that language processing in the human brain is hierarchical, starting from the auditory analysis to language production, and depending on the specific neuroanatomical structures. Language processing involved the comprehension and production of language.

Language comprehension was often associated with Wernicke's area discovered by Carl Wenickes in 1874. Wernicke's area, primarily located in Brodmann area 22 (BA 22) of the superior temporal gyrus (STG), lies at the posterior segment of STG adjacent to the supramarginal gyrus (DeWitt and Rauschecker, 2013), extended to the middle temporal gyrus (MTG) and angular gyrus (AG), superior temporal sulcus, planum polare, planum temporale and Heschel's gyrus (Jäncke et al., 2021).

The anterior STG (aSTG) will start the word recognition process (DeWitt and Rauschecker, 2013) and phonological analysis when the information was presented auditorily. The information then travels posteriorly in the STG to the planum temporale. The posterior STG (pSTG) then processes the semantic and syntax features of the stimulus. The STG mainly supports the retrieval of phonological forms used for speech output and short-term memory tasks (Binder, 2017).

Howbeit, words presented visually or in written form evoke the visual processing area in the brain located at the occipital lobe. The information is processed at the primary visual area (BA 17) before it passes to the secondary visual area (BA 18) (Friederici, 2011). Later, the information submitted to the angular gyrus (AG) occupies between the central and posterior branches of the caudal superior temporal sulcus (Segal and Petrides, 2013) to map the visual input to linguistic representation (Liuzzi et al., 2019). The linguistic information then travels to STG and IFG for the subsequent process.

Meanwhile, Broca's area architectonically lies at BA 44 and 45 or the inferior frontal gyrus (IFG). The pars opercularis and the pars triangularis are two structures that made the Broca's area (Jäncke et al., 2021). The function of Broca's area includes both comprehension and production of language.

Previous studies focused on two cortical structures accountable for syntactic processing, namely the superior temporal gyrus (STG) and inferior frontal gyrus (IFG) (Reynoldcs et al., 2019; Shetreet and Friedmann, 2014; Xu et al., 2020a). The STG and IFG are illustrated in Figure 2-1. The aSTG is activated during the processing of sentences containing syntactic and semantic violations, while the pSTG is activated during processing syntactic information (Friederici, 2011). The processing of syntactic ambiguity activated the posterior temporal lobe extending posteriorly to the inferior parietal lobe and the MTG anterior to Heschl's gyrus. IFG activated during processing syntactically complex sentences. It also supports building syntactic structure, assigning thematic roles, and computing the syntactic movement (Friederici, 2011; Wells et al., 2009). Figure 2.1 showed the language related brain regions.

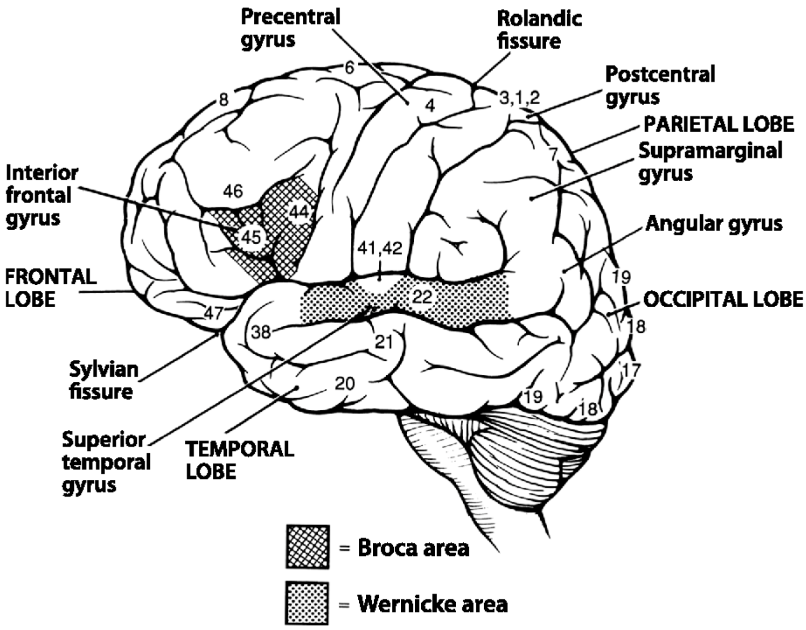

Figure 2.1: Language.related brain region The image was acquired from Gill, D. J., & Damann, K. M. (2015).

In addition, language functions were predominantly lateralised to the left hemisphere (Alexandrou et al., 2017).The left posterior inferior frontal gyrus (pIFG) and pSTG influenced the syntax and semantic analysis in sentence comprehension task (Kroczek et al., 2019). In spite of that, the right hemisphere's role is just as important as the left hemisphere in sentence comprehension (Federmeier et al., 2008; Riès et al., 2016). Damage to the right hemisphere led to difficulty in understanding discourse and speech perception (Luthra, 2021).

2.3 Malay language relative clause

For many years, psycholinguists have studied the relative clause in various languages because it has a unique embedded structure that can modify the prior element in that particular sentence (Harding et al., 2019; K. Xu et al., 2020a). The relative clause can manipulate syntactic complexity in a sentence (Xiong and Newman, 2020).

The relative clause is the type of sentence or clause anchored to the head of a noun phrase and deviated from the basic Subject-verb-object (SVO) word order (Antinucci et al., 1979). The Malay language relative clause is usually embedded with the marker *yang* in the noun phrase (Bakar et al., 2016). The current study focused on two relative clauses: the Subject relative clause (SRC) and the Object relative clause (ORC). Table 2.1 showed the basic canonical SVO and the non-canonical SRC and ORC.

Table 2.1: Example of the clause in Malay and English. The clauses are SVO, SRC, and ORC.

Number	Type of clause	Example of the clause in Malay and English
Sentence 1	SVO	Kakak menyiram nenek *The girl pours water to grandmother*
Sentence 2	SRC	Kakak yang menyiram nenek *The girl that pours water to grandmother*
Sentence 3	ORC	Kakak yang nenek siram *The grandmother that the girl pours water*

The agent in the sentence must precede the theme for the canonical structure as demonstrated in sentence 1 in table 2.1, *The girl pours water to grandmother,* the agent (*kakak/* the girl), verb (*siram/* pours water), and theme or object (*nenek/* grandmother). The SRC, as shown in sentence 2 in table 2.1, is embedded by the marker *yang*/ that, and the structure closely adheres to the SVO word order (Wells et al., 2009; Bakar et al., 2016). The ORC, as in sentence 3 in table 2.1 also embedded by the marker *yang*/ that as the SRC. The ORC was identified as non-canonical because the theme was placed before the agent. For further explanation, Table 2.2 illustrated how ORC and SRC were transformed from basic SVO word order.

Table 2.2: The transformation process of SRC and ORC from basic SVO word order

Type of clause	Transformation process
SVO	[$_s$ Kakak] [menyiram] [nenek] agent/subject verb theme/object
SRC	1. [$_s$ Kakak […… menyiram] [nenek] – movement of word *menyiram* for embedment process 2. [$_s$ Kakak [yang menyiram] nenek] – embedment of marker *yang* 3. [$_s$ Kakak [$_{s'}$ yang [menyiram]] nenek]
ORC	1. [$_s$ Kakak menyiram] [nenek] – movement of word *nenek* (theme) 2. [$_s$ Kakak nenek] [menyiram] ……. 3. [$_s$ kakak [...... nenek]] [menyiram] – movement of word *nenek* for the embedment process 4. [$_s$ Kakak [$_{s'}$ yang nenek]] menyiram] – embedment of marker *yang* 5. [$_s$ Kakak [$_{s'}$ yang nenek]] menyiram] - abortion of morpheme *men-* in *menyiram* 6. [$_s$ Kakak [$_{s'}$ yang nenek] siram]

2.4 The Dependency Locality Theory (DLT)

As a sentence structure increased in its complexity, higher cognitive loads were needed to process that sentence. Thus, Gibson (2003) proposed the dependency locality theory (DLT) to explain complex syntactic structures like SRC and ORC. This theory explained the association of the sentence processing mechanism and the cognitive load needed. The DLT has two components to predict the syntactic complexity: the integration cost and memory cost.

The integration cost referred to syntactic movement in the sentence. The longer the distance of a syntactic structure moved to the head of a noun phrase, the greater the integration cost involved (Futrell et al., 2020; Gibson, 2003). While the memory cost explained how working memory maintained the prediction when there is syntactic movement in the sentence. The more syntactic movement involved, the greater the working memory load needed. The movement of the agent to the NP in ORC and the embedding process of marker *yang* in the SRC sentence best described how the integration cost and memory cost worked. The example of the syntactic movement and the working memory load described in table 2.3.

Table 2.3: Example of the syntactic movement in Malay relative clause of SRC and ORC

Number	Type of clause	Example of syntactic movement
Sentence 1	SRC	$[_s$ Kakak $[_{s'}$ yang [menyiram]] nenek] *The girl that pour water to grandmother*
Sentence 2	ORC	$[_s$ Kakak $[_{s'}$ yang nenek] siram] *The grandmother that the girl pours water*

In both SRC of sentence 1 and ORC of sentence 2 in table 2.3, the verb of the relative clause *siram/* pour was dependent on the preceding relative pronoun. In SRC, these two words were usually adjacent. The embedment of marker *yang/* that have generated short syntactic movement, thus not requiring a high working memory load to maintain the prediction.

However, in ORC, they were separated by the agent (*kakak/* the girl), which caused a higher integration cost and more significant memory cost (Gibson, 1998; Temperley, 2007). This evidence showed that computing the ORC is more complicated than SRC, making it significantly hard to comprehend. This statement also supported by neuroimaging study that found significant neuronal activation during ORC comprehension than SRC (Just et al., 2009). Numerous studies also found that ORC is more difficult to comprehend than the SRC due to its canonical structure (Carreiras et al., 2010; Wells et al., 2009). The irregular sentence structure increased the sentence complexity and required a higher cognitive load to depict the sentence (Xiong and Newman, 2020).

2.5 The functional Magnetic Resonance Imaging (fMRI)

In recent years, the amount of linguistic study using functional Magnetic Resonance Imaging (fMRI) had grown significantly (Shetreet and Friedmann, 2014; K. Xu et al., 2020a). Through fMRI, the cerebral presentation of comprehension or production of language could be justified. The present paper also using fMRI to study the relative clause among L1 and L2 Malay language speakers.

There are a few advantages in mapping language areas using fMRI. It is a non-invasive neuroimaging modality and very safe to use on unhealthy subjects. The fMRI uses the Blood Oxygen Level Dependent (BOLD) signals to modulate the neural activation, which is neural activation during language processing. It has a small voxel size that can produce a high-quality image due to good spatial resolution, even with an acceptable temporal resolution. The fMRI data are registered with very high-resolution images that enable the researchers to understand the association between the functions and anatomic structures. Besides, the activation procedures can be performed repeatedly in the same subject. Hence it can measure test-retest reliability and allow researchers to monitor the changes over time while studying various cognitive processes.

From the fMRI, the neuronal activations at the region of interest (ROI) of language functions like the inferior frontal gyrus, superior temporal gyrus, and the prefrontal cortex can be studied, as well to determine the functional connectivity related to language such as arcuate fasciculus (Black et al., 2017).

The fMRI also allowed researchers to use various stimuli to study language processing, such as visual and auditory. The block design is effective in detecting neural activation. In contrast, the event-related design is excellent for understanding the haemodynamic response function from a single event (Chee et al., 2003).

In the current study, the researchers apply the sentence and visual stimulus with the block design to study the neuronal activation during comprehension of relative clauses among native (L1) and non-native (L2) Malay language speakers.

2.6 Relative Clause Comprehension Among L1 And L2

The study of relative clause comprehension was conducted in many languages such as English (Chen et al., 2006; Pliatsikas et al., 2017), Chinese (K. Xu and Duann, 2020; K. Xu et al., 2020b, 2020a), Korean (Mansbridge et al., 2017), Ixcatec (Adamou, 2017), Spanish (García-Orza et al., 2017), Malay (Bakar et al., 2016) and sign language (Krebs et al., 2018). The preference of the type of relative clause comprehension was also diverse due to the language structure itself. The language that has SVO word order like Malay and English have difficulty comprehending ORC. Whereas the language that has the final-head position, like Chinese, understand ORC better than SRC.

It happened because the relative clause had a complex syntactic structure. Comprehending relative clauses was a convoluted process and demanded multiple brain regions to serve it. Many previous literature focused on the activation of the inferior frontal gyrus and superior temporal gyrus (Vigneau et al., 2006; K. Xu and Duann, 2020; K. Xu et al., 2020b, 2020a). However, further research had found that comprehension of relative clauses also employed the other brain region, such as the parietal, occipital and insula (Bulut et al., 2018; Carreiras et al., 2010; Vogelzang et al., 2020).

The presentation of the relative clause to the recipient, either through auditory or visual (orthographic), also influenced the brain region involved (Walenski et al., 2019). The strong activation at the occipital region was related to word recognition during the reading task (Qu et al., 2017). Meanwhile, the sentence presented auditorily elicited strong activation at the temporal region (Harding et al., 2019; Lee et al., 2018; Vogelzang et al., 2020).

Working memory played a critical role when processing complex syntactic structures like relative clauses. The unusual word order (Yadav et al., 2020) caused reanalysis and restructuring (Krebs et al., 2018; Xiong et al., 2019) of every element in the sentence. It was proven from the prior research that working memory enhanced the effective connectivity from LIFG to LSTG upon processing complex sentences (K. Xu and Duann, 2020; K. Xu et al., 2020a, 2020b). Processing complex syntactic structures also involved multiple brain networks such as ventral attention network (VAN), language network (LN), and default mode network (DMN) (Xiong and Newman, 2020).

Furthermore, comprehension of the relative clause is depending on the speaker's ability too. Previous literature discovered that L1 and L2 utilised different brain regions in comprehending relative clauses (Golestani et al., 2006). The discrepancy was contributed by few factors like grammatical knowledge (Perani and Abutalebi, 2005), age of acquisition, length of exposure to the language, and proficiency level (Golestani et al., 2006; Sulpizio et al., 2020). However, no past study was conducted in Malay language relative clauses that utilised the neuroimaging modality. Therefore, the neural activation of the L1 and L2 of Malay language speakers cannot be detected and differentiated.

Table 2.4 summarised the past studies regarding relative clauses using neuroimaging modalities such as fMRI, EEG/ERP, and eye-tracking. While table 2.5 presented the past research on relative clause comprehension without using neuroimaging modality.