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A preliminary fMRI study of relative clause in comprehension among native and non-native Malay language speakers

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Abstract: This study investigates (a) whether there is a functional neural activation at the frontal and temporal brain regions during the comprehension of Malay relative clause (RC), and (b) the differences in the activated areas among native (L1) and non-native (L2) Malay language speakers. The subject relative clause (SRC), object relative clause (ORC), and subject-verb-object (SVO) were used as the study stimuli. Participants were asked to do a sentence-picture matching task during an fMRI measurement. The random-effect analysis (RFX) using two-way ANOVA was conducted for the fMRI data. The main effect of the group at the $p_{uncorrected} < 0.001$, 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 as distributed to the frontal, temporal, parietal, and occipital regions that lateralised to the right hemisphere. Conclusions: The findings suggested that the comprehension of Malay relative clauses had caused the activation at different brain regions amongst L1 and L2 groups. It was also found that both L1 and L2 groups showed their preference in SRC, the mean reaction time showed that they had a faster reaction time to comprehend SRC than 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; fMRI, neuroimaging;

1.0 INTRODUCTION

The ability to comprehend sentences from resources enables us to respond to the messages being delivered. On the contrary, when a person fails to understand the sentence, it will cause them to miss critical information and eventually experience a breakdown in communication. For example, individuals with agrammatism, such as aphasic, will have difficulty in 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 begins with syntactic and lexical parsing, assigning thematic roles, and finally, building the conceptual representation of the sentence (<u>Friederici, 2011</u>). Moreover, sentence comprehension is also a sophisticated process that requires multiple brain regions to serve the operation. This phenomenon has fascinated many researchers to study the sentence comprehension process in the brain (<u>Karlsson et al., 2019</u>; <u>Meltzer, et al. 2010</u>; <u>Rodd et al., 2015</u>; <u>Walenski</u>

et al., 2019). They have used various neuroimaging modalities, such as the electroencephalogram (EEG) (Harding et al., 2019; Xiong & Newman, 2021), with event-related potential (ERP) and functional magnetic resonance imaging (fMRI) (Lee et al., 2016; Xu et al., 2020a), to examine the neural substrate underlying the sentence comprehension process. From those neuroimaging techniques, the researchers have found the involvement of frontal and temporal brain regions (Bulut et al., 2018; Xu et al., 2020b).

The relative clause was often used as the research stimulus to observe the neuronal activation related to sentence comprehension. This is considering that in the relative clause, the order of arguments does not follow the subject-verb-object. The relative clause is the noncanonical sentence in which the sequence of its syntactical structures deviated from the usual word order. Hence, we learn that in a relative clause, the theme precedes the agent, which makes the sentence more complex and difficult to process (Walenski et al., 2019). The Malay relative clause is marked with the syntactic structure yang, which is embedded in the noun phrase. Acquisition of a 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 nonnative (L2) speakers.

2.0 MATERIALS AND METHODS

Research design

This study was an observational study with a quantitative cross-sectional design. The data were only collected once. The functional neuronal activations in L1 and L2 participants were observed and compared in both groups. No intervention was conducted on the participants in this study.

Participants

Data collection was carried out at the MRI suite, Department of Radiology, Hospital Universiti Sains Malaysia, Kelantan. The study population consists of Malaysians who are native and non-native Malay language speakers. The sample size was calculated based on the suggestion by Desmond & Glover (2002). In this paper, power analysis was used to determine the sample size. In the present study, the researcher only managed to conduct a study on eight participants (mean age 23.4-year-old). In this paper, a power analysis was

used to determine the sample size. In the present study, the researcher only managed to conduct a study on eight participants (mean age 23.4-year-old). Even though the present study utilises a small sample size design, it still enables us to understand the pattern of comprehension of relative clauses. It could provide basic knowledge for future study that is related to comprehension. Following this study, it is possible to give a future direction on predicting the exact quantitative effect sizes at least in some Regions of Interest. At the experimental level, prior to time constraint, MRI machine fault, and limited financial source, therefore the overall several practical limitations often beyond the control of researcher restrict increasing participant in this study, as well as COVID-19 pandemic, has given rise to some notable difficulty in this study that involving human participants. Four participants were from the L1 group and another four from the L2 group. For L1 & L2 participants, their inclusion criteria were the same, except that L1 must be a native speaker of the Malay language (L1) and Malay language is their first language. He/she speaks standard Malay language and is not influenced by any dialect, such as the Kelantanese dialect. For L2, the participant must be a non-native speaker of the Malay language (L2) and the Malay language must be their second or third language. He/she should speak the standard Malay language and is not influenced by any dialect, such as the Kelantanese dialect. The inclusion and exclusion criteria for L1 and L2 participants were as follows:

Inclusion criteria, participants must:

- Never been diagnosed with any speech & language problems.
- 2. At the age range of 18 to 40 years old.
- 3. Possess a grade A or at least a grade B or equivalent grade in SPM level Bahasa Melayu examination.
- 4. Have a normal or corrected-to-normal vision.
- 5. Be able to give own consent.

Exclusion criteria, participants must not:

- 1. Be diagnosed with any speech & language problems.
- 2. Have any related metal implantations, for instance, orthopaedic metal implantation at any parts of the body, pacemaker, dental braces, or tattoo.

fMRI Paradigm

The fMRI paradigm for the present study has been adapted from Zaidil et al., (2019). This fMRI paradigm employed a block design. The block design was chosen

because it is simpler and there is no need for discreet randomisation of conditions. The block design also has a superior statistical power, in which it can tell the subtle changes in BOLD signals over different conditions (Chee et al., 2003). The fMRI paradigm was developed using e-prime 1.0 software before the data collection process started.

A total of 69 Malay language relative clauses consisting of 23 SRC (condition 1), 23 ORC (condition 2) and 23 SVO (condition 3) sentence stimuli paired with 69 visual stimuli were assigned for this study. Those threesentence conditions were randomised entirely across the three runs. The paradigm contained 69 active blocks of 23 SRC trials, 23 ORC trials and 23 SVO trials, and 72 rest blocks. This study paradigm started with a fixation cross for 10s, followed by an active block of any condition for 10.5s, and a 10s rest block between the active blocks.

The single trial started with the sentence stimulus. The sentence stimulus could be ORC or SRC, or SVO that was presented for 5 seconds. Then, it was followed by a blank screen for 0.5 seconds and a binary visual pictorial stimulus afterwards. When a binary visual pictorial stimulus appeared on the screen, the participant needed to press the button (1) to choose the picture (A) or button (2) to select the picture (B). The whole timeline for a single trial for each condition was 10.5 seconds. The timeline for a single trial for the SRC, ORC, and SVO conditions (see **Figure 1 a, b, & c** are as follows:

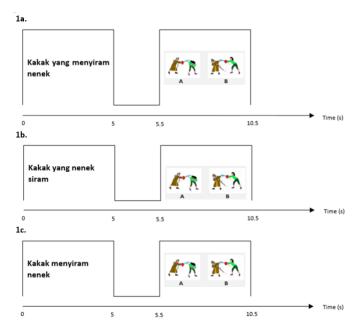


Figure 1: (a) Timeline of a single trial for SRC condition. **(b)** Timeline of a single trial for ORC condition. **(c)** Timeline of a single trial for SVO condition.

An estimated 474 seconds or 7.9 minutes were needed to complete one run of the study paradigm. The overall time length for this experiment was 1422 seconds or 23.7 minutes, where these came from 724.5 seconds or 12.08 minutes of active blocks and 697.5 seconds or 11.63 minutes of rest blocks.

2.3 Data collection method and study procedure

There were two (2) phases in the data collection process. The first phase was data collection before going for the MRI scanning procedure. In this phase, participants filled in the demographic form and Edinburgh Handedness Inventory-short form (Veale, 2014) based on the Edinburgh Handedness Inventory (Oldfield, 1971). Two sets of questionnaires were provided to ensure all participants fulfilled the inclusion criteria and socio-demographic characteristics.

The second phase was where the participants underwent the fMRI scan. The participants were required to answer 69 questions about the Malay language relative clauses during the scan and matched corresponding binary visual Approximately 68.7 minutes were needed to complete the whole experiment. This data collection process was conducted once to every participant, so it required a one-time visit from all participants. The first step in the study procedure was acquiring consent from the participant. After signing the informed consent form, the researchers ask the participant to fill in the demographic and Edinburgh Handedness Inventory-Short forms (Veale, 2014). Then four participants were assigned to the native speaker (L1) group and another four participants to the non-native speaker (L2) group. Both groups had their practice sessions outside the MRI scanner, ahead of the real study inside of the MRI scanner. The participant got used to the experiment conditions containing 3 SRC, 3 ORC, and 3 SVO in the practice session. Inside the MRI machine, a brain scan was taken before the fMRI task scan was initiated.

fMRI Data Acquisition

The MRI images were acquired using a 3.0 Tesla MRI scanner, Philips Achieva (Philips Achieva, Philips, Best, The Netherlands), with a 16-channel whole-head coil. Under fMRI, the participant's head was immobilised with a vacuum-beam pad. The functional blood oxygenation level-dependent (BOLD) signals were acquired with T2*-weighted echo-planar imaging (EPI) sequence. The specific parameters used were slice thickness of 3.4mm and no gap, in-plane resolution of 3.03 × 3.01 × 3 mm, and TR/TE/flip angle=2000 ms/10ms/78°. The field-of-view was 20 cm, and the

acquisition matrix was 68×73 . The first five volumes and last one volume of the run were discarded for signal equilibrium to get 231 image volumes in one run. T1-weighted sequence (TR=2000 ms/TE=1.49) was used to obtain fine-grained localisation information of the fMRI activity, producing a high-resolution anatomical brain image of each participant. This sequence used 192 sagittal slices to cover the whole brain, resulting in an isotropic spatial resolution of $1.1 \times 1.1 \times 1.2$ mm³. Duration for the fMRI data acquisition was 1422 seconds or 23.7 minutes. The language block design was employed in this study.

fMRI data analysis

Initially, the raw brain scan images that we acquired were recorded in DICOM files. The MRI convert, developed by Robert and Beverly Lewis Center for Neuroimaging at the University of Oregon, was used to convert DICOM into FSL NIfTI file. Before proceeding with the pre-processing step, visual inspection was done to ensure no abnormality of the structural image (T1). The brain scan images were pre-processed using the latest Statistical Parametric Mapping 12 (SPM 12) software package on the MATLAB 2018b (MathWorks, Natick, Ma). The pre-processing step was done to remove the uninteresting variability from the data to produce high-quality images. This step was also important to prepare the data to analyse all scans of each subject into a standard space. The pre-processing step began with realigning and unwarping process because the earlier visual inspection found that the participant moved substantially during scanning. These realigning and unwarping steps were carried out for motion correction. It used a 4-degree B spline with no unwarp. The images were registered to mean. In this step, the files with the prefix *u* were created.

Next, slice time correction to correct the misalignment was carried out. The brain was scanned slice by slice as the fMRI could not scan them simultaneously, which then caused the slices to be momentarily misaligned from each other (Parker and Razlighi, 2019). The brain was sliced into 40 slices for this study, with TR = 2 and TA = 1.95. Files with the prefix α were generated from this step. The third step in pre-processing was segmentation. This step allowed us to measure and visualize different brain structures. Thus, the brain image was separated from the surrounding tissues. This step used the anatomical image (T1-weighted). Then, structural images were fitted to the East-Asian brain template. Next, the images were calculated. These steps put together the GM, WM, and CSF into one and was corrected for bias field by multiplying these added images by a bias-corrected image. The images were then coregistered and estimated. In this step, the subject's fMRI data were aligned to its anatomical image, and then estimated. Then, normalisation and write-up procedures were carried out. This step was similar to the coregistration, but it aligned and wrapped FMRI data to the generic anatomic template such as MNI atlases. Files with the prefix w were created from this normalisation step.

The last step in pre-processing was smoothing. This step aimed to blur the functional images to correct any remaining functional and anatomical differences between the subjects. The first-level analysis was conducted to create the general linear modelling (GLM). It used the equation of $y = x\beta + \varepsilon$. The variable y was the functional folder containing three conditions: SRC, ORC, and SVO. The variable x referred to the three runs of the conditions. The variable β was considered as unknown and was to be calculated in the next processing steps. The ε was a constant. Thus, in this study, the GLM was y = $(x0\beta0) + (x1\beta1) + (x2\beta2) + \varepsilon$. In this step, the SPM.mat was produced. The estimating step was conducted to calculate the β . The design matrix for each condition was created in this step. For example, the design matrix for SRC was 1 0 0 0, ORC was 0 1 0 0, and SVO was 0 0 1 0. Thus, the result for one subject was revealed. The next step was the group-level analysis. In this step, a new GLM was created, and the estimate step was also repeated. The new design matrix was created and data were processed according to the group, native (L1) and non-native (L2) speakers. The second-level analysis was conducted to compare the brain activation across the subjects in the group, as mentioned in the research objective. Thus, the random field analysis with the factorial ANOVA was applied. In this study, the type of clauses (SVO, SRC, and ORC) and speaker groups (L1 and L2), both were independent variables. Statistical analysis was performed at P uncorrected < 0.0001. The pipeline of fMRI analysis to find the functional brain activation among L1 and L2 Malay language is illustrated in Figure 2.

The AAL Atlas, Brodmann Area (BA) atlas

The prior analyses were then traced and compared to the AAL atlases to ensure accurate location. The Brodmann Area (BA) atlas was also used to number the BA area of each brain region activated from the Malay relative clause comprehension.

Statistical Analysis

Additional statistical analysis was carried out using the IBM Statistical Package for Social Sciences (SPSS)

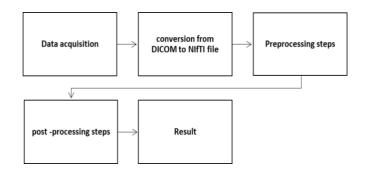


Figure 2: Pipeline of fMRI data analysis for the relative clause comprehension among native and non-native Malay speakers.

Statistics version 24 to calculate the mean reaction time for each condition and compare it between the groups. The accuracy and reaction time of the comprehension question of SRC, ORC, and SVO from all eight participants were recorded and analysed. Firstly, all the inaccurate answers were removed. Thus, only the reaction time with accurate responses were calculated. The normality test was also administered. It was found that responses from each condition were normally distributed from the skewness and kurtosis value. Next, the one-way repeated measure ANOVA was conducted for both L1 and L2 groups. The reaction time for each condition was the dependent variable, while the speaker's group was the independent variable. The oneway repeated measure ANOVA was chosen because the participants were subjected to more than one condition, and the response to each condition was later compared. This was based on the assumptions that the dependent variable was continuous, independent variables in this study were categorical and normally distributed, no significant outliers, and the variance of the differences between all the combinations of related was equal. The sphericity was tested using the Maulchy's test, with the significance level > 0.05.

3.0 RESULTS

This section outlines the data interpretation results, which included the participant's demographic result, behaviour result of accurate reaction time, and brain functional activation result.

Demographic results

A total of 8 participants participated in this study and they were assigned into the L1 and L2 groups equally. **Table 1** shows the distribution of participants of both groups and the details of their age range, gender, ethnicity, SPM Bahasa Melayu result, handedness, and influence of the dialect.

Behaviour results

The accuracy and reaction time (RT) of the responses to comprehension questions of the Malay language relative clauses were documented. Only RT of the accurate responses were selected after the removal of the outliers. The mean reaction time for native (L1) and non-native (L2) groups will be further discussed.

Table 1: Demographic data of native (L1) and non-native (L2) participant.

Variables		Nativ		Non-native (L2) (N = 4)		
		N (%)	Mean (SD)	N (%)	Mean (SD)	
Age (years)	23 – 25		24.2 (1.25)		23.5 (0.43)	
Gender	Male Female	1 (25) 3 (75)		3 (75) 1 (25)		
Ethnicity	Malay Chinese Indian	4 (100) - -		2 (50) 2 (50)		
SPM Bahasa Melayu	Grade A Grade B	4 (100)		4 (100) -		
Handed- ness	Right Left	4 (100) -		4 (100) -		
Dialect	Yes No	- 4 (100)		- 4 (100)		

N, number of participants; %, percentage; SD, standard deviation

Reaction time for L1

The one-way repeated measure ANOVA was conducted to compare the mean reaction time of SRC, ORC, and SVO conditions in the L1 group. The result is depicted in **Table 2**.

The results showed no significant difference between the condition in L1 group (F (2,82) = 2.43, p = 0.094, η^2 = 0.056. However, a direct comparison showed that SRC (1774.48 seconds) was slightly faster than SVO (1973.88) and ORC (21.38.38) in response to the task given.

Reaction time for L2 groups

The mean reaction time for conditions SRC, ORC, and SVO for the L2 group also was analysed using one-way repeated measure ANOVA. The result of the analysis is shown in **Table 3**.

The result showed no significant difference between the conditions F(2,54) = 3.13, p = 0.052, $\eta^2 = 0.104$. The reaction time for each condition was 1824.50 seconds for SRC, 2083.39 seconds for ORC, and 2260.18 seconds for SVO. Similar to L1, direct comparison showed the L2 group had a faster reaction time to comprehend the SRC than SVO and ORC.

Table 2: Mean reaction time of conditions for L1 group.

Conditions	Mean RT (95% CI) (seconds)	F-stat (df)	<i>p</i> -value	Partial Eta Squared
SRC	1774.48 (1562. 79, 1986.16)			
ORC	2138.38 (1830.65, 2446.10)	2.43 (2,82)	0.094	0.056
svo	1973.88 (1694.22, 2253.54)	_		

Table 3: Mean reaction time of condition for L2 group.

Conditions	Mean RT (95% CI) (seconds)	F-stat (df)	<i>p</i> -value	Partial Eta Squared
SRC	1824.50 (1576.03, 2074.97)			
ORC	2083.39 (1788.06, 2378.72	3.13 (2,54)	0.052	0.104
svo	2260.18 (2008.26, 2512.09)			

Functional brain activation of native (L1) group and non-native (L1) group

Two-ways ANOVA in random field (RFX) analysis was conducted to identify and compare the brain activation between the L1 and L2 groups. The group of Malay language speakers (L1 and L2) and the conditions (SRC, ORC, and SVO) acted as the independent variables (IV) within the subjects and between the groups. The regions with the statistical threshold of $p_{\rm uncorrected} < 0.001$ and cluster size >20 voxels were selected to avoid Type 1 errors. This is considering that false positives could occur, when the regions activated had resulted from noise, and not from the true effect (Lieberman and Cunningham, 2009; Slotnick, 2017).

Together, the above results provided important insights into the understanding of the Malay relative clause comprehension. With respect to the first research objective, it was found that Malay relative clause comprehension had activated the frontal and temporal brain regions in L1 and L2 groups. **Table 4** has presented

the main effect of group (L1 and L2) and the main effect of conditions (SRC, ORC, and SVO) between the subjects. The main effect of the group demonstrated the activation at the left and right superior parietal lobule (SPL), left middle temporal gyrus (MTG), left superior temporal gyrus (STG), left precentral gyrus (PrG), left supramarginal gyrus (SMG), left middle frontal gyrus (MFG), and right occipital fusiform gyrus (OFuG) at $p_{uncorrected}$ < 0.001. The activation can be observed in Figure 3a. However, no functional brain activation was indicated for the main effect of the condition. The post hoc comparison was carried out to explore the L1 and L2 brain activation. Table 5 have indicated the comparison of L1 > L2 and L2 > L1 group at p_{uncorrected} < 0.001. The comparison of L1>L2 has activated the left SPL, left SMG, left MTG, left STG, Left PoG, Left PrG, and right OFuG. Meanwhile, the L2 > L1 has activated more areas at the right hemisphere such as right SPL, right PoG, right superior frontal area, right middle occipital gyrus (MOG), right inferior occipital gyrus (IOG), and left FuG. The L1>L2 activation can be

seen in **Figure 3b** and the activation of L2>L1 in **Figure 3c**. From this analysis, the differences of activation between the L1 and L2 groups managed to be differentiated. Another post hoc analysis was computed to explore the positive effect between the L1 and L2 groups. The neural activations were detected at left SPL, left SMG, left STG, left PrG, left PoG, left SMG, left OFuG, and left precuneus (PCu). **Figure 3d** has depicted the positive effect of group L1 and L2. The positive effect condition activated the left SPL, left PrG, left MFG, right IOG, left MTG, and left STG. The details of the result can be observed in **Table 6** and **Figure 3e**.

Conjunction analysis was implemented to compare the activation across the group of L1 and L2. However, no significant activation was found between the groups. The same analysis was done to the SRC, ORC, and SVO conditions and compared between the L1 and L2 groups. This analysis also found no significant neural activation. Thus, it was presumed that there was no significant activation, regardless of the conditions and group, with respect to the conjunction analysis. In accordance with the present results, we will discuss the location of the functional neural activation and differences between L1 and L2 Malay language speakers' groups during the comprehension process of Malay relative clauses. The L1 and L2's ability in comprehending the relative clauses will also be addressed here.

Table 4: The main effect of group (L1 and L2) at $p_{uncorrected}$ < 0.001 and the main effect of condition (SRC, ORC, SVO) at $p_{uncorrected}$ < 0.001, cluster size > 20 voxels.

Cluster level	Peak level	Coordinate		Location		
kE	Voxel F	Х	у	Z	BA	Brain region
92	87.39	-25	-46	35	7	L SPL
22	75.54	-49	-49	5	21, 22	L MTG, L STG
27	74.75	-46	-16	32	3, 4, 40, 46	L PoG, L PrG, LSMG, L MFG
57	58.88	30	-40	59	7	R SPL
25	48.73	23	-85	-13	37	R OFuG
	kE 92 22 27 57	kE Voxel F 92 87.39 22 75.54 27 74.75 57 58.88	kE Voxel F x 92 87.39 -25 22 75.54 -49 27 74.75 -46 57 58.88 30	kE Voxel F x y 92 87.39 -25 -46 22 75.54 -49 -49 27 74.75 -46 -16 57 58.88 30 -40	kE Voxel F x y z 92 87.39 -25 -46 35 22 75.54 -49 -49 5 27 74.75 -46 -16 32 57 58.88 30 -40 59	kE Voxel F x y z BA 92 87.39 -25 -46 35 7 22 75.54 -49 -49 5 21, 22 27 74.75 -46 -16 32 3, 4, 40, 46 57 58.88 30 -40 59 7

kE, cluster level; voxel F, generated by F contrast; BA, Brodmann's Area; L, Left; SPL, superior parietal lobule; MTG, middle temporal gyrus; STG, superior temporal gyrus; PoG, Postcentral gyrus; PrG, precentral gyrus; SMG, supramarginal gyrus; MFG, middle frontal gyrus; OFuG, occipital fusiform gyrus

Table 5. Multiple comparison of L1 > L2 and L2 > L1 group at $p_{uncorrected}$ < 0.001, cluster size > 20 voxels \circ

	Cluster level	Peak level		Coordinate			Location		
	kE	Voxel T	х	у	Z	BA	Brain region		
Native (L1) > non- native (L2)	114	9.35	-25	-46	35	7	L SPL, L SMG		
	30	8.69	-49	-49	5	21, 22	L MTG, L STG		
	32	8.65	-49	16	32	3, 4, 40	L PoG, L PrG, L SMG		
	29	6.98	25	-85	-13	37	R OFuG		
	74	6.52	5	-13	50	32	R MCgG		
	84	7.67	30	-40	59	7, 40	R SPL, R PoG		
Non-native (L2) > native (L1)	31	6.40	11	66	55	11, 12	R Sup frontal area R MSFG, R SFG		
. ,	21	6.17	36	-73	8	18, 17	R MOG, R IOG		
	69	6.06	-39	-46	-4	37	L FuG		

kE, cluster level; voxel T, generated by T contrast; BA, Brodmann's Area; L, Left; R, right; SPL, superior parietal lobule; SMG, supramarginal gyrus; MTG, middle temporal gyrus; STG, superior temporal gyrus; 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.

4.0 Discussion

4.1 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

The present study revealed the functional neural activation related to Malay language syntax for native (L1) and non-native (L2) Malay language speakers. Our main hypothesis expected that there would be neural activation during the comprehension of the Malay language SRC and ORC at the frontal and temporal region for both groups. Indeed, the activation at the MFG at the frontal brain region and the STG at the temporal region were observed from the fMRI analysis. This finding is in line with the study by Vogelzang et al.

(2020) and Xu and Duann (2020), where they also found the activation of the frontal and temporal region during the processing of relative clauses.

Processing non-canonical structures like the SRC and ORC requires the extensive roles of the frontal and temporal brain regions. However, the frontal and temporal brain regions' function in processing SRC and ORC sentences is explicit. The frontal region is engaged for learning syntactic rules of a language, syntactic parsing, and sequencing words in order hierarchically for the sentence that is non-canonical (Xu and Duann, 2020). Not only that, the frontal region is also associated

Table 6: Positive effect of group and positive effect of condition at $p_{uncorrected} < 0.001$, cluster size > 20 voxels

	Cluster level	Peak level	Coordinate			Location		
	kE	Voxel T	х	у	Z	BA	Brain region	
Positive effect group	114	9.35	-25	-46	35	7	L SPL, L SMG	
	30	8.69	-49	-49	5	21, 22	L MTG, L STG	
	32	8.65	-49	16	32	3, 4, 40	L PoG, L PrG, L SMG	
	29	6.98	25	-85	-13	37	R OFuG	
	28	6.52	5	-52	32	7	R PCu	
	28	16.92	-25	-61	53	7, 40	L SPL	
Positive effect of condition	22	13.03	-46	1	41	4, 46	L PrG, L MFG	
	55	11.22	33	-88	2	18, 17	R IOG	
	69	10.26	-22	-88	-1	21,22	L MTG, STG	

kE, cluster level; voxel T, generated by T contrast; BA, Brodmann's Area; L, Left; R, right; SPL, superior parietal lobule; SMG, supramarginal gyrus; MTG, middle temporal gyrus; STG, superior temporal gyrus; PoG, Postcentral gyrus; PrG, precentral gyrus; OFuG, occipital fusiform gyrus; Pcu, Precuneus; MSFG, superior frontal gyrus medial segment; SFG, superior frontal gyrus; MOG, middle occipital gyrus; IOG, inferior frontal gyrus.

with working memory and executive function (Walenski et al., 2019).

The STG (BA 21) that occupies the temporal region is responsible for integrating the semantic and syntactic information in a sentence. STG also supports the working memory needed in processing argument-verb relations of complex sentences (Xu and Duann, 2020).

Another important cortical structure located in the temporal region is the MTG (BA22). The MTG is adjacent to the STG and is implicated as a semantic processing hub (Middlebrooks et al., 2016) and involves deductive reasoning during the sentence comprehension process (Xu et al., 2015). A tractography study by Xu et al. (2015) revealed the anterior MTG function in sound recognition and semantic retrieval. The middle MTG is obligated to the semantic memory and semantic control network (Xu et al., 2015).

4.2 The differences in functional neural activation of Malay language syntax different for native (L1) and non-native (L2) Malay language speakers

Findings of the study revealed the functional neural activation related to Malay language syntax for native (L1) and non-native (L2) Malay language speakers. Our main hypothesis expected that the comprehension of the Malay language SRC and ORC would activate the frontal and temporal region for both groups. The prime area activated at the frontal brain region was the MFG, while for the MTG and STG, activation was at the temporal brain region. This finding is in line with previous researches where they also found the

activation of the frontal and temporal region during the processing of English (Pliatsikas et al., 2017), Mandarin (Bulut et al., 2018), Chinese (Xuan et al., 2020a, b), and the Austrian sign language's relative clause (Krebs et al., 2018). Processing non-canonical structures like SRC and ORC requires the extensive roles of the frontal and temporal brain regions. In the study, the frontal and temporal brain regions' function in processing SRC and ORC sentences was explicit. The frontal region is engaged for learning syntactic rules of a language, syntactic parsing, and sequencing words in order hierarchically for the non-canonical sentence (Xu & Duann, 2020). The frontal region is also associated with working memory and executive function in sentence comprehension tasks (Walenski et al., 2019).

The STG (BA 21) that occupied the temporal region is responsible for integrating semantic and syntactic information in the sentence. STG also supports the working memory needed in processing argument-verb relations of complex sentences (Xu et al., 2020b). Another important cortical structure located in the temporal region is the MTG (BA22). The MTG is adjacent to the STG, is implicated as a semantic processing hub (Middlebrooks et al., 2016), and involves deductive reasoning during the sentence comprehension process (Xu et al., 2015). A tractography study by Xu et al. (2015) have revealed the anterior MTG function in sound recognition and semantic retrieval. The middle MTG is obligated to the semantic memory and semantic control network (Xu et al., 2015).

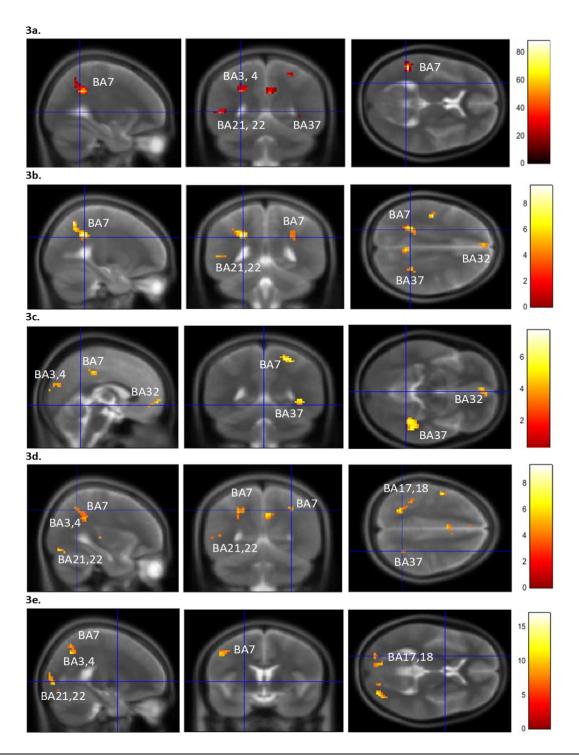


Figure 3 a. The main effect of the group at p uncorrected< 0.001. The figure represents the section view with activation at BA 3 (postcentral gyrus) and BA 4 (precentral gyrus), BA 7 (superior parietal lobule), BA 21 (superior temporal gyrus), and BA 22 (middle temporal gyrus). **b.** Multiple comparison of L2 > L1 at puncorrected < 0.001, cluster size > 20 voxels. The figure represents the section view with activation at BA 7 (superior parietal lobule), BA 32 (middle cingulate gyrus) and BA 37 (occipital fusiform gyrus). **c.** Multiple comparison of L2 > L1 at puncorrected < 0.001, cluster size > 20 voxels. The figure represents the section view with activation at BA 7 (superior parietal lobule), BA 32 (middle cingulate gyrus) and BA 37 (occipital fusiform gyrus). **d.** Positive effect of group at puncorrected < 0.001, cluster size > 20. The figure represents the section view with activation at left and right BA 3 (postcentral gyrus), BA 4 (precentral gyrus), BA 7 (superior parietal lobule, precuneus) and BA 21 (middle temporal gyrus), BA 22 (superior temporal gyrus) and BA 37 (occipital fusiform gyrus). **e.** Positive effect of condition at puncorrected < 0.001, cluster size > 20. The figure represents the section view with activation at BA 3 (Postcentral gyrus), BA 4 (Precentral gyrus), BA 7 (superior parietal lobule), BA 17, 18 (inferior occipital gyrus), BA 21 (middle temporal gyrus), BA 22 (superior temporal gyrus). The crosshair here does not show the target location but the position of brain activation at the same or different planes at the same slice.

4.3 The differences in functional neural activation of Malay language syntax between native (L1) and non-native (L2) Malay language speakers

It was hypothesised that different functional neural activation was underlying the Malay language relative clause processing among the L1 and L2 groups. The neuroimaging result showed that activation of the L1 group has focused on the temporo-parietal region. Meanwhile, the collection of regions involving the frontal, temporo-parietal, and occipital regions were activated during the comprehension of the Malay relative clause on the L2 group. Past literature supported L1 and L2 as activating different brain regions during the processing of non-canonical sentences (Golestani et al., 2006; Sulpizio et al., 2020).

In the analysis of the native (L1) > non-native (L2) group, it found the activation of the SPL, SMG, STG, middle temporal gyrus (MTG), precentral gyrus (PrG), and postcentral gyrus (PoG). Most of the L1 participants' activation was lateralised to the left hemisphere and focused on the temporo-parietal part. The insignificant activation of the frontal region in L1 was because the frontal region is only functioning when the task was difficult, which demanded higher cognitive function (Walenski et al., 2019). In that sense, we postulated that the L1 group had no difficulty comprehending the clauses, and the tasks were effortless. Contrary to the L2 group that recruited many brain regions, including the superior frontal area (SFA), to process the Malay relative clause.

As aforementioned, the analysis of the non-native (L2) > native (L1) group triggered the activation of various brain regions in processing the non-canonical Malay relative clause. The comprehension of the SRC and ORC caused the recruitment of the right SPL, right PoG, and right SFA, which involved superior frontal gyrus (SFG), right middle occipital gyrus (MOG), right inferior frontal gyrus (IOG), and left FuG. In L2, the activation that lateralised to the brain's right hemisphere was noticed, indicating that the right hemisphere is equally important as the left hemisphere in SRC and ORC comprehension. In sentence processing, the right hemisphere is liable for assigning the meaning and context of the words (Federmeier et al., 2008; Luthra, 2021; Riès et al., 2016). Therefore, the intense activation at L2 has presumed that it was related to processing unpredicted semantic relation (Federmeier et al., 2008) of non-canonical SRC and ORC. A study by Qi et al. (2019) showed a similar finding as ours, where the L2 had the most activation at the right hemisphere and was associated with neural reorganisation due to foreign language learning. According to the neuroimaging data, the L2 group required additional brain regions to process Malay relative clauses compared to the L1, which focused on the temporoparietal region. The neural reorganisation contributed to the distinct functional brain activation during second language learning (Chen et al., 2020; Liu et al., 2020). Hence, it also caused stimulation of secondary language areas such as the middle frontal gyrus (MFG), that served in the language switching (Sierpowska et al., 2018)

Past research has also observed the activation of sensory-motor areas during comprehension of action words or verbs (<u>Boulenger et al., 2009</u>). In a study by Tian et al. (2020), the activation of SMG, PrG, and PoG during the action-related-language comprehension task were demonstrated among L1 and L2 Chinese speakers. Although the L1 and L2 groups had shown diversion activation at different brain regions in the study, they shared the same activation at the motor area. Findings in past literature have been confirmed in this study, where we observed the activation of the sensory-motor area precisely at SMG, PrG, and PoG during the comprehension of SRC and ORC. Furthermore, Schaller and colleagues (2017) have suggested the profound activation of sensory-motor areas pertinent to processing abstract and concrete sentences containing the action words.

Besides, the study also discovered the activation at the parietal, supramarginal gyrus, and occipital region. The superior parietal lobule (BA 7) had the most cluster activation compared to the other brain regions during the comprehension of the Malay language relative clause. This finding is supported by the study from Zaidil et al. (2019), which have found temporo-parietal region activation during the processing syntax of Malay language embedded with Wh-question. The activation of the parietal region, together with the supramarginal gyrus (SMG) in the present study, was associated with second language learning in L2 (Barbeau et al., 2017). Besides, SPL also implicated non-linguistic tasks such as memory, attention, and emotion (Kamali et al., 2014). In addition, the involvement of secondary language areas such as the Fusiform gyrus (FuG) was also activated. The FuG is a higher processing area for visual information. It is also known as the visual word form area (WFA), which is bound in recognising words during reading (Gerrits et al., 2019). Enhanced activation of FuG is linked to novel word learning (Qu et al., 2017), especially in L2. It is thought that modulation of the FuG

in this study was also due to the sentence stimuli presented visually.

4.4 Comprehension ability of Malay language relative clause among L1 and L2

The behaviour data showed an interesting finding related to the mean reaction time of accurate answers regarding the comprehension of Malay relative clause across the L1 and L2 groups. It was found that L1 could comprehend Malay relative clauses faster than L2. Previous statistical analyses confirmed that both groups had a faster reaction time in understanding SRC, followed by SVO and ORC. Therefore, we postulated that the Malay SRC was easier to comprehend than ORC by L1 and L2. The current finding has concurred with the previous research in the language which has SVO word order such as English (Pliatsikas et al., 2017), and language that has free word order such as Basque (Arantzeta et al., 2017) and German (Harding et al., 2019).

Processing complex sentence structures like ORC required a high cognitive load for ordering and storing the information (Xu et al., 2020b). This is parallel with the Dependency Locality Theory (DLT) (Gibson, 2000), which has pointed out that working memory could influence sentence comprehension. For instance, in the ORC, the movement of 'object' in the verb phrase to the head of the noun phrase causes a high working memory capacity to order the word to fill the subject gap and maintain the predicted noun head.

In addition, factors like sex could influence the syntax processing competencies of a person (Xu & Duann, 2020). This study had an imbalance of males and females in the L1 and L2 groups, leading to significant language ability gaps between these two groups. It can be seen in the reaction time of correct answers, where the L1 generally had a faster reaction time compared to the L2. L1 had more females in the group, and L2 had the male majority. This phenomenon explained why L1 has a cluster activation focused on the temporo-parietal regions. It has been justified in the research by Sato (2020) that females had superior activation at the temporal region during the speech perception and production tasks. Xu & Duann (2020) have also confirmed that women have better language processing ability, better dynamic interaction, and integration of brain networks during language processing. Therefore, it has enlightened why L2, which has a male majority, demanded multiple brain regions to process Malay relative clauses.

Besides, the L2 capacity in Malay relative clause comprehension was affected by a few external factors such as the age of L2 acquisition, proficiency level, amount of language exposure, manner of acquisition, modality of acquisition and frequency of language switching (Połczyńska et al., 2017). These factors supplemented the neural plasticity in the brain, which later affects the language processing ability. The majority of the participants acquired L2 via formal route during their preschool age. Although those participants were fluent in Malay, they still show an ability gap in their language processing, as demonstrated in the neuroimaging data, where they use many secondary language areas to comprehend Malay relative clauses.

5.0 CONCLUSIONS

This study revealed how the Malay relative clauses had modulated neural activity. The comprehension process of the Malay relative clause, namely the SRC and ORC, has indeed activated the frontal and temporal brain regions. Using the fMRI modality, the differences in the functional neural activations were detected. It was found that the functional neural activation for L1 was focused on the temporo-parietal region. On the other hand, the functional neural activation for L2 was distributed to the frontal, temporal, parietal, and occipital regions. The recruitment of multiple brain regions in L2 indicated that comprehension of the Malay relative clause was difficult for them. The additional analysis has also found that the SRC is easier to comprehend than the ORC by both, the L1 and L2 groups. It occurred because the syntactical structure of the ORC is more complex, which then requires the higher working memory capacity to process it.

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Author Contributions: NBS performed the experiments, authored the paper and analysed the data; JHY contributed the materials; and AIAH participated in (a) planning and supervising the work and (b) discussed the results and commented on the manuscript.

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