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AMBIGUITY IN SEMANTIC INTEGRATION: A DECOMPOSITIONAL ANALYSIS BY ERP

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ABSTRACT

The present study used Event-Related Potentials (ERPs) to analyse ambiguity in semantic integration for sentence-picture matching task. This task includes two sub-processes: Spatial Indexing and the assignment of spatial relations between the located object and the reference object. Based on the shown stimuli, participants were divided into two groups (processing either intrinsic reference frame or relative reference frame). Result showed the presence of N400 in semantic integration. Easiness in spatial indexing was indicated from increased amplitude of P300 while cognitive cost incurred by each reference frame on spatial language processing was inferred by the reduction in amplitude of N4. Participants showed greater mental effort when cognitive processing was done using intrinsic reference frame.

KEYWORDS: Sentence Picture Matching Task; Spatial Index; Spatial Reference Frame(SRF); Semantic Integration; Event Related Potential (ERP).

INTRODUCTION

Consider a scenario where a person is asked the question "Where is the pet shop?" and the response obtained is "It is next to the Bakery". Even with this answer, a person would find it difficult to locate the pet shop because he/she may interpret the response with respect to their perspective as being left to the bakery while it might actually mean to be situated behind the bakery according to the other's perspective. Herein, the pet shop is the located object while the bakery is the reference object. This difficulty in establishing an unambiguous interpretation of the relation between the located and reference objects reflects the complexity of spatial language which is prevalent in most cultures. In Spatial language, the Spatial Reference Frame (SRF) used to view the scene majorly contributes to the integrity of its semantic integration and hence, an ambiguity may arise in the linguistic and visual interpretation of a scene/sentence depending upon the perspective of the viewer. Spatial language gets even more complicated when the scene has multiple plausible interpretations, prompting a perplexing semantic mapping of a spatial term onto a scene. For example, as shown in Fig.1, how the spatial relation between the car and ball will be defined depends on the SRF used. Both of the following statements describe the picture correctly: (i) The ball is to the left of the car. (ii) The ball is in front of the car. The participants who select the first as the relation between the ball and car use the relative SRF, while the one's selecting the second relation would be using the intrinsic SRF.

The objective of the present study is to investigate the role of SRF in the ambiguity arising in understanding spatial language for a sentence-picture matching task. To measure the differences that may arise while processing ambiguities it is important to formulate such methods that either activate a particular RF or enable the assessment of the subjective changes in the meaning of a constant objective perceptual stimulus. ERP recordings are well suited for such studies as it can illustrate the time-course of cognitive processing and have been able to provide converging evidence and illustrate both reference frame activation and selection processes

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[1,2]. The measurable parameters of ERP are amplitude, latency and scalp topographies. We considered only the amplitude because the latency remains constant for any linguistic manipulation [3]. P3 and N4 were the

Figure 1. Spatial scene showed spatial relation between ball and car.

parameters chosen owing to previous studies that have well established their roles in semantic integration [4,2,5].Furthermore, to gauge the arising ambiguities, a two-step 'sentence-picture matching' task (involving semantic integration) applies a decompositional approach. The first step is 'spatial indexing' which involves the establishment of a link between the conceptual representation consisting of spatial predicates derived from the sentence and the perceptual representation consisting of objects and surfaces derived from the picture [6]. With regard to ERP, we expect amplitude modulation of P3. This modulation is associated with event categorisation as defined by Kok [7] as a process that leads to a decision regarding whether the external stimulus matches an internal representation of a specific category of stimuli. Second step is 'assigning spatial relations between two objects' in which the involvement of SRF is more evident[8].This step would be reflected by the amplitude modulation of N4.

In one monumental study, N4 was used to elucidate the underlying reference frame processing involved in the semantic integration for a picture sentence verification task [2]. They provided converging evidence for the role of N4 in semantic integration and that it could differentiate the relative SRF from the intrinsic SRF. ERP results showed a greater value of N4, peaking between 300 and 375 ms, when the intrinsic frame was not used. While their results were highly significant, our results were not expected to follow exactly similar patterns. The reason being that instead of asking for the spatial relation after showing a picture, in our study, a sentence that described a spatial relation was given to the participants before showing the picture. According to a previous study, the differentiation of intrinsic and relative reference frames starts early at the level of sentence processing [9], due to which a decompositional approach in Sentence Picture Matching task was used for this study instead of the Sentence Picture Verification task. The results were captured through ERP recordings.

The choices of the SRF are an integral part of the linguistic relativity hypothesis [10] which shows that languages may use one or more frames of reference, namely intrinsic and relative SRF. An intrinsic reference frame pertains to an object's or person's coordinate such as near, before etc. The relative reference frame includes the egocentric coordinates (view centred) such as left, right, front and back. In our study, we have taken into consideration the relative reference frame and the intrinsic reference frame as ambiguities arise primarily due to these two SRFs [8]. This study tried to measure real time cognitive processing for different subjective perspective for misaligned stimulus through go-nogo paradigm wherein the go stimuli consisted of pictures for which the true reflection of the problem was to be assessed, and pictures irrelevant to the problem were given as no-go stimuli.

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Methods

Participants

Total 40 children (12 to 14 years, 29 males and 11 females) participated in the experiment. This study is one part of a future comparative study that would repeat the given procedure for adults to draw inferences on the effect of age on ambiguities in semantic integration, and hence, children were the primary participants of this study.

Materials

In a pilot study to establish the adequacy of the presented stimuli, explicit spatial relations of a man (having intrinsic sides) and a ball (without intrinsic sides) were presented as a go-nogo Sentence Picture matching task (Fig.2). It was conducted on 17 participants to see whether presented go stimuli was strong enough to gauge the semantic reference frame processing involved in semantic integration. Result showed significant amplitude modulation of N4 between go-nogo stimuli, $t(169)=5.166$, $p<0.01$. Result was inline to the Taylor et al. [2] which showed that SRF processing involves the role of N4 and semantic integration.

In this study, total two pictures constituted the presented misaligned stimuli, such that one invoked the Intrinsic SRF, while the other invoked the Relative SRF and the groups were matched with the age and sex of participants [9]. The go stimuli were constructed in Photoshop with a white background. No-go trials included random pictures from the Google image database. At a viewing distance of about 70 cm, the object subtended 6° of visual angle as shown in Fig.3 and Fig. 4.

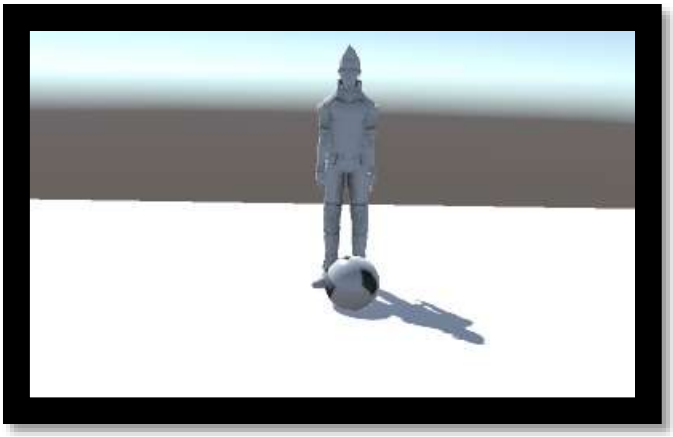

Figure 2. Explicit relation between the ball and the man in a canonical form as used in pilot study.

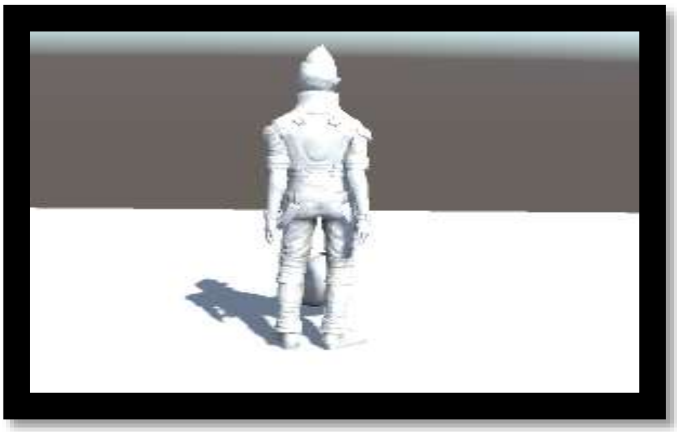

Figure 3. Spatial relation between ball and man promoting intrinsic frame of reference

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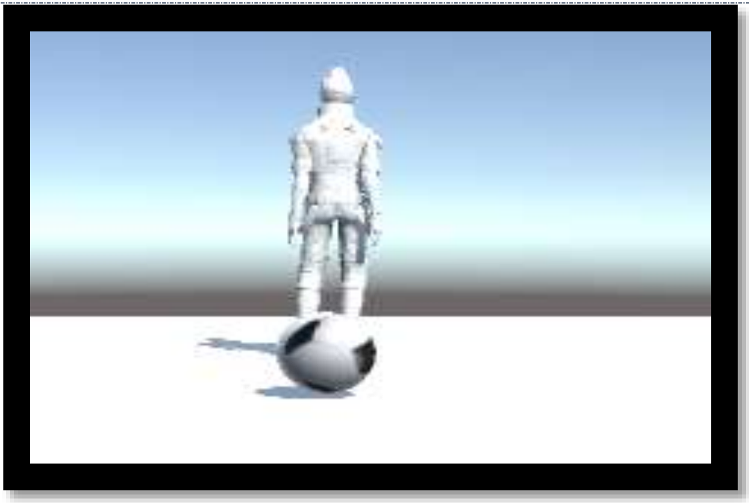

Figure 4. Spatial relation between ball and man promoting relative frame of reference

In stimulus, spatial relations between the man and the ball were similar to that in the pilot study (in front of each other). Same picture from pilot study also need to be added, but in different spatial configurations of reference object that constituted for misaligned stimuli. It reflected the similarity in spatial indexing but difference in understanding of spatial relations between the two groups. This difference indicates the variation that stems from understanding the same sentence with different subjective interpretation inclined toward a particular SRF. All such variations were assessed through amplitude modulation of ERP waveforms. Presented stimuli were different for both groups. Group I (Intrinsic) was subjected to a go stimulus which evoked the intrinsic reference frame while Group R (Relative) was given a go stimulus that evoked the relative reference frame.

Apparatus

The Nexus 10 system was used to obtain ERP recordings. The Sampling frequency was 256 Hz, with a total window size of 600ms. A Bipolar configuration was used in which the positive electrode was taken as Cz and the negative electrode as Pz. These sites were typical for the expression of P3 and could capture the modulation of interest well [8]. One ground electrode was placed at the left mastoid. Impedance level was kept below 5 kilo ohm. A Bandpass filter was applied for 0.1 to 45 Hz, while the gain factor was kept at 19.5. The range of the obtained ERP signals was between -40 to 40 micro-volts.

Significance of ERP: The Scalp ERP waveforms showed an averaging of the time series changes in the electrical brain activity recorded before, during and after an event of interest. P3 is used to determine the veridicality of a spatial description that entails working memory updating and final decision [4]. The P3 amplitude is also proportional to the amount of attentional resources engaged in processing a given stimulus [11]. Another ERP parameter, N4 is a monophasic negativity between 200 and 600 ms, largest over centro-parietal sites [3]. Its amplitude increases with the increasing mental effort involved in semantically integrating a stimulus in its context like a picture [12,13].

Procedure

The experiment was conducted in a noise free environment under the guidance of an instructor. Consent forms were filled by the participant's parents. The study was conducted in the premises of the school with permission from the authorities. The participants were told to remain calm and were informed of the importance of the study.

They were requested not to blink during the course of a single trial and also to minimize body movements during the experiment. Bipolar Cz-Pz electrodes were placed on the scalp of participants with the help of a gel. A two minute baseline recording was taken to check the quality of the signals and to boost motivation in the participants. Two one-minute baselines were obtained for eyes closed and eyes open conditions respectively. Only one sentence "The ball is in front of the man" was told in the English language. The participants were instructed to evaluate if the sentence reflects adequately the scene in the upcoming presentation. Then, trial began with 'let's begin' signal, where participants pressed 'Enter' to begin the trial. Each trial had four go stimuli and sixteen no-go stimuli, total of twenty stimuli. Each stimulus appeared for 600 ms, followed by interstimulus interval of 300 ms. Go-nogo stimuli were presented randomly. Go stimulus was a spatial scene in a misaligned form that remained the same for all the trials. Total 30 trials were received by each participant during the experiment. ERP was recorded during the go-nogo presentation. A total of 15 minutes were taken to complete the sentence picture matching task with inter task interval of 10 second.

Result

Of the 40 participants, 20 were shown stimuli using the intrinsic reference frame and the other 20 were given stimuli in the relative reference frame.
Epoch Analysis: A baseline period of 10 seconds was taken before presenting the stimuli. The total window length was 1000ms and mean amplitude was computed using the Biotrace software for P3 (window length= 250-500). The code for the calculation of N4 was scripted in Matlab and computed for a range of 250ms to 600ms. Atmost four trials were rejected from raw data due to artefacts by visual inspection. The largest postitive peak appearing after 250ms was taken as P3 amplitude.
As established in a previous paper [2] , the negativity component peaked at approximately 325 ms. The amplitude of the first largest negativity (N4) that appeared was taken into consideration. After obtaining the features of N4 and P3, a statistical t-test was applied using the SPSS software. Statistical significance was determined by the size of the difference between the group averages, the sample size, and the standard deviations of the groups. A two-step analysis procedure was executed for go-nogo trials separately for the both groups. A first grand average of the results was computed per participant, to later calculate a grand average one (group wise). One way Anova was applied on grand average to observe changes between the trials of go-nogo and for comparing go trials between the groups with a significance level of 0.05($P < .05$).
There was a remarkable difference in the amplitude of N4 in the go-nogo task for Group I (Intrinsic), $F(1,38)=5.89, p=.00$ (Fig. 5) and Group R (Relative) , $F(1,38)=10.96, p=.00$ (Fig. 6). Go stimulus had a more significant negative amplitude for Group I, $F(1,38)=3.419, p=.006$ (Fig. 7). Also, there was great difference in the amplitude of P3 for group I, $F(1,38)=3.40, p=.001$, and group R, $F(1,38)=2.23, p=.027$.

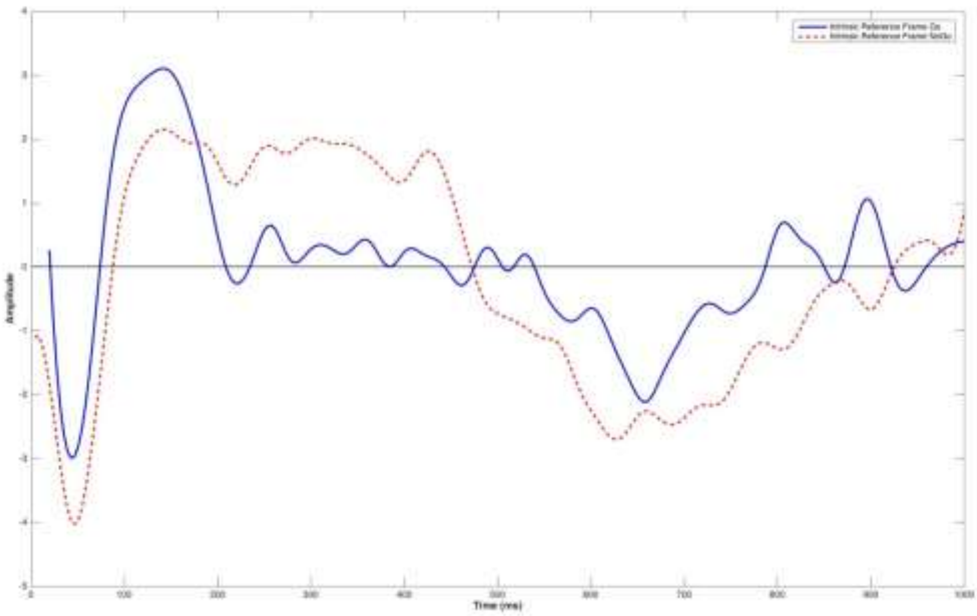

Figure 5. ERP waveforms for intrinsic reference frame (Group I)

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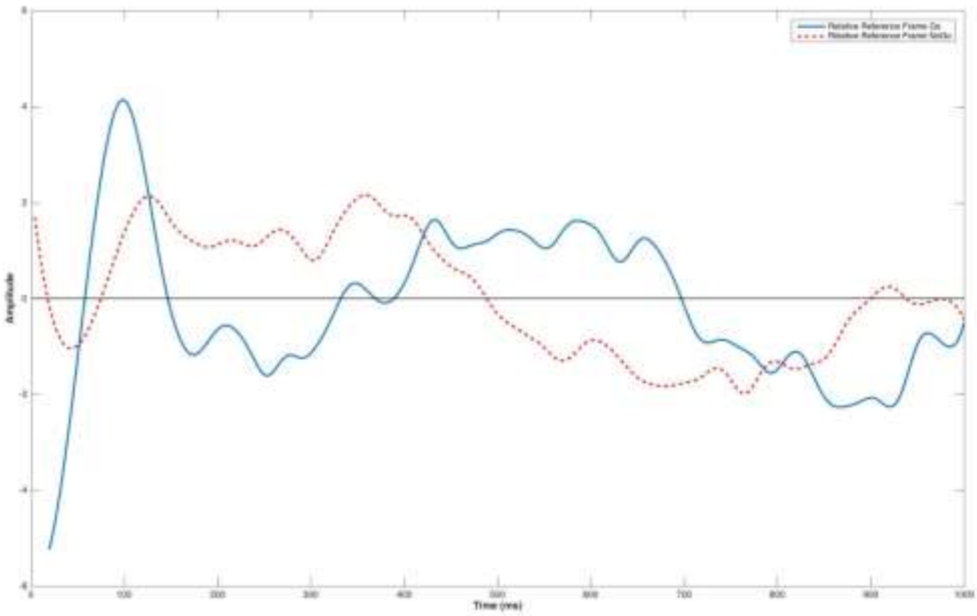

Figure 6. ERP waveforms for relative reference frame (Group R)

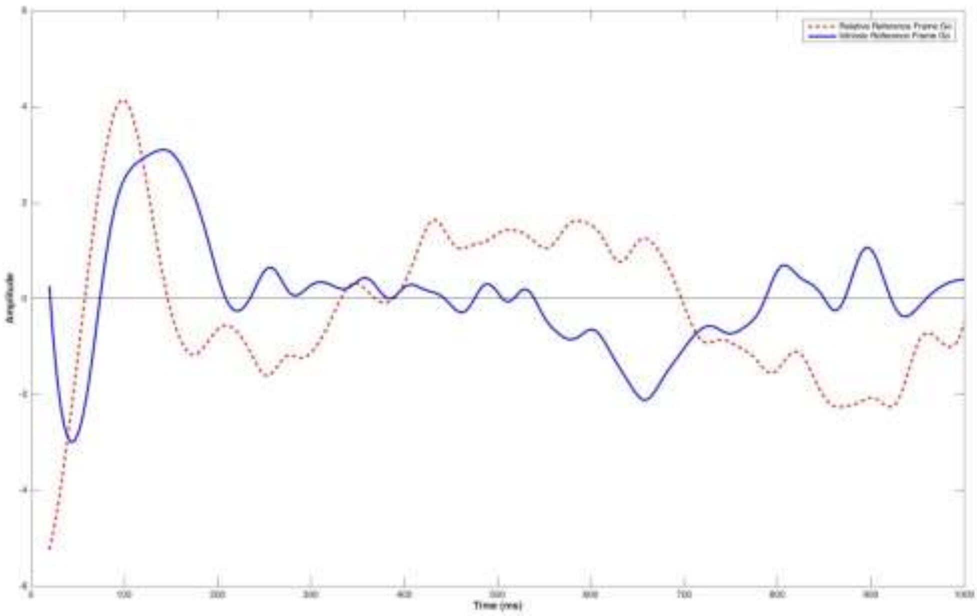

Figure 7. ERP waveforms describing difference between go stimuli in different reference frame of processing

Discussion

In the present ERP study, we investigated the amplitude modulation for P3 and N4 involved in semantic integration using decompositional approach. Ambiguity can arise when a perceptual stimulus has misaligned SRF that can confer different subjective interpretation for a constant stimulus. To measure such ambiguities, sentence-picture matching task was performed in a go-nogo paradigm. The focus in this task was on mapping the sentence through the two step process of spatial indexing and the establishment of spatial relations between the objects in the picture; each subprocesses was associated with the different ERP parameter.

P300

Within the group analysis showed significant amplitude modulation of P3 which indicative of event categorisation for the presented stimulus. As alluded to earlier research, non-canonical stimuli increased difficulty in mapping conceptual representation onto perceptual representation and this difficulty could be reflected in reduced amplitude of P3 [8]. Similarly, our result showed amplitude modulation for P3 between go and nogo stimuli for misaligned SRF. In other words, P3 was found to be an indicator for spatial index. Between the groups analysis showed reduced amplitude of P3 for Group R signifying the greater attentional effort put by participants. The amplitude of P3 is considered to be an index of the attentional capacity invested in determining the task relevance of a given stimulus [7]. Thus, spatial indexing for Group R was more difficult as the participants put more attention to interpret the sentences intrinsically. For instance, when the sentences were fully processed intrinsically it might become easier for the participants to simply map the picture following the sentence on the intrinsic representation, as reflected by the ease in mapping of Group I as compared to Group R. Another reason why participants of group I had easiness in spatial indexing than group R could be that they first see the scene, interpret it to later match it with the spatial terms, and in doing so, they put a priority on the intrinsic interpretation. The nature of images used in the study could also have influenced the results of P300, and made it difficult for the participants to perform spatial indexing. The Sentence-Picture matching task required the mapping of sentences with pictures that were presented as misaligned stimuli. This could also be a factor in the reduced amplitude of P3 as the rotation of the reference object increases the difficulty of the identification process, requiring additional attentional resources and resulting in greater difficulty in mapping the sentence and picture together [8]. In summary, amplitude modulation of P3 was present for non-canonical stimulus, indicated difficulty in spatial indexing for group R.

N400

Within the group analysis showed significant amplitude modulation of N4 for both the groups, validating the role of semantic integration in sentence picture matching task. Between the groups analysis revealed amplitude modulation for N4 under the influence of SRF, significantly more for group I. Results showed an increase in the amplitude for group I, which could be due to the additional cognitive cost incurred during processing using the intrinsic reference frame. This finding was found to be in opposite to [2] where a larger N400 was associated with the relative reference frame. The reason could be due to a difference in the adopted task (sentence picture verification). It was also mentioned that participants had to derive information from their memory when picture was not available (verification process) and it put extra demands on the participants for integrating information which was not required in our study because it require matching of sentence onto spatial scene. However, her work also lent to one conclusion that N400 should be evident in any situation requiring semantic processing; a larger N400 could be attributed to information that is more difficult to integrate. The ambiguity of multiple SRFs was also said to increase the difficulty of semantic integration. Another factor that appears for the absence of increased activity in Group R might be that the differentiation of intrinsic and relative reference frames started early at the level of sentence processing [9]. In summary, presented stimulus evoked process of semantic integration; Additional cost was incurred when cognitive processing was performed in an intrinsic reference frame.

Our results converge with a previous fMRI study that tracked the neural correlates of the ambiguities arising from use of Intrinsic and Relative SRFs [9].The results showed the importance of reference frame in the cognitive processing of a spatial scene. It also pointed out that spatial language requires a categorical rather than a metric spatial conception involved in perception. Finally, distinct neural correlates were present for an abstract semantic parameter in language, namely the frame of reference in an interpretation of ambiguous spatial scene. Thus, the brain dynamics were differentiated during spatial indexing through P3 and the association of spatial relations between objects with the help of amplitude modulation of N4. It also highlighted complexity in processing for each reference frame within the processes of the task. For example, participants in relative reference frame found processing difficult in spatial indexing as reflected by P3 while participants in intrinsic reference frame found difficulty in assigning spatial relations as reflected by N4.

CONCLUSION

This study demonstrated the influence of distinct SRFs in the semantic interpretation of a linguistic string and delineated the significance of using a particular SRF in processing the literal sense of a sentence. The results also provided for rich insights into the variations in cognitive costs experienced by the subjects adhering to a particular frame of reference. This study is unique in that it is one of the few studies that attempt to find out the effects of SRF on linguistic string processing through the use of ERP markers. Also, it tries to apply decompositional approach to apprehension through N4 and P3. Although this study did not measure the behavioural response of the participants, if the overall performance of Group I and Group R had been equivalent, then it could be inferred from the results of this study that the Intrinsic SRF could be associated with difficulty in semantic integration while the Relative SRF could imply greater attentional effort. However , this research faced a limitation in terms of single bipolar electrodes used and the limited brain regions taken into consideration. The scope of this study can be extended in the future trough studies that could gain an insight into making an adaptive instructional and display design, as preferred by the subject for applications in fields such as marketing, education, defence and interfacing where great stress is laid on interpretation and understanding.

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