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Electroencephalographic characteristics of word finding during phonological and semantic verbal fluency tasks

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Abstract

Aims: Verbal Fluency is sensitive to brain damage and is employed to assess language abilities like the size of vocabulary and the semantic-lexical networks' integrity and executive functioning abilities particularly inhibition, working memory, and self-monitoring. Various studies revealed oscillatory changes related to word retrieval during different tasks. However, there are not enough studies on electroencephalographic characteristics of word retrieval routes (phonological or semantic pathway) during free recall. The purpose of our study was to investigate electroencephalography power relationship with semantic and phonological word finding routes during verbal fluency.

Methods: In this within-subject study, the electroencephalography of 20 healthy participants was recorded during written category and letter fluency tasks and compared with the rest state. Absolute power of the signals in delta (1-3.5 Hz), theta (4-7.5 Hz), alpha (8-12 Hz), and beta (12.5-30 Hz) was calculated in three lobes (frontal, parietal, and temporal).

Results: A repeated measures ANOVA showed significant interaction of condition × lobe × frequency × side ($P < .001$). Post hoc test for each lobe showed significant changes in the absolute power of delta, theta and beta for frontal, delta and theta for parietal, and theta and beta for temporal lobes (P-values < .05).

Conclusion: Searching the words by phonological entries is associated with decreased beta and increased theta in left frontal lobe. These changes are not necessary for semantic word retrieval strategy.

KEYWORDS
category verbal fluency, EEG absolute power, letter verbal fluency, word finding routes

1 | INTRODUCTION

Word retrieval, as a core to language production, requires the activation of conceptual and word representations in memory whose result is selecting the correct word. Its essential role is evidenced by the strong influence of deficits in word retrieval such as anomia. Nonetheless, in spite of the significance of word retrieval for language and the huge societal and personal costs caused by its disruption due to neurological disorders, the neural basis of retrieval is poorly understood.[1]

To explore the lexical access, some researchers prefer to employ verbal fluency tasks in which the respondents are required to produce as many words as possible belonging to a semantic category in a minute (category fluency) or to begin with an assigned letter (letter fluency)[2] because of their demands which make them applicable for both normal and impaired children and adults to assess language abilities like the size of vocabulary and the semantic-lexical networks' integrity, knowledge of word's phonological features and executive functioning abilities, particularly inhibition, working memory, and self-monitoring,[3–6] as well as their sensitivity to brain damage. Therefore, verbal fluency tasks are utilized in studying non-clinical samples to assess their verbal ability, namely lexical retrieval ability and lexical knowledge[7–9] and also assessing the executive control ability.[10,11]

Serious deficits in either executive control or verbal ability would be manifested by poor performance in fluency tasks. Thus, fluency tasks can be used as an effective screening instrument for evaluating the general verbal functioning.[3]

Different types of word finding difficulties (ie, semantic substitutions and phonological errors)[12,13] and various levels of performance are seen in letter versus category fluency in age-related disorders such as Alzheimer's disease in which category fluency is remarkably influenced, while letter fluency remains fairly intact.[14,15] Different neural basis of anomia treatment (phonological and semantic) in aphasia[16] might indicate two pathways for lexical access. A dorsal pathway connects posterior superior temporal cortex to the inferior frontal gyrus (IFG) through the superior longitudinal fasciculus, and is assumed to carry out phonological and syntactic functions, such as speech production and perhaps phonological short-term memory. A ventral pathway extends the length of the temporal lobe, crossing into ventral IFG (BA 44/45) through the extreme capsule and uncinate fasciculus and is involved in semantic processing.[17,18]

Neuroimaging studies on anatomical correlates of word retrieval also indicate that there are shared and distinct neural basis underlying semantic and phonological word finding, as temporal activation is associated with semantic word generations while frontal cortical activity reflects phonological processes.[5,19–21]

Electroencephalography (EEG) with excellent temporal resolution might shed light more on the neural mechanism of language processing. The electrophysiological changes that come with free recall will possibly not to be related to a single neural signal.[22] Previous studies have suggested that alpha-beta power decrease might indicate word retrieval processes[23–26] and theta wave activity is specifically related to encoding and retrieval which seem imperative to success in verbal fluency tasks.[27]

Various studies revealed oscillatory changes in theta, alpha, beta, and gamma related to word retrieval during different tasks such as memorization of lists of either concrete or abstract nouns[28] and picture naming for sentence completion[29] and predicting the word during sentence processing in which sentential context facilitates lexical retrieval.[30] However, few studies have directly tracked the frequency bands' changes and revealed word retrieval routes (phonological or semantic pathway) during free recall. For instance, Brickman et al[14] study on EEG power relationship with category and letter verbal fluency showed increased theta power related to category fluency. However, theta specific and offline EEG recording were two important shortcomings of that study which prevented depicting a clear neuropsychological picture of word retrieval.

This study aimed to have a real-time investigation of electrical activity in language-related areas of healthy participants during verbal fluency task in which contextual facilitation does not exist. Therefore, EEG activity during category and letter verbal fluency tasks was analyzed in delta, theta, alpha, and beta frequency bands to explain word finding difficulties in different neurogenic language disorders. Electrophysiological knowledge of word finding could be used in the realm of emerging neuromodulatory techniques such as EEG biofeedback.

2 | METHODS

2.1 | Participants

The sample included 20 college students (eight males and 12 females) aged between 18 and 30 years who were conveniently selected from university students who met the inclusion criteria, that is, normal or corrected vision and being right-handed. Those who had the history of neurological, psychiatric, or psychological disorders or used medications which influence nervous system or were unwilling to participate in the study were excluded.

2.2 | Materials

The standard Persian fluency test developed by Ebrahimipour[31] was used in the present study.[31] The reported correlation coefficient and Cronbach's Alpha were 0.99 and 0.81, respectively. To prevent EMG noise and artifacts during recall, the participants were asked to produce written responses.

2.2.1 | Category fluency task

This task included three categories namely, fruits, animals, and clothes. The respondent was required to write the subcategories of each category as quickly as possible in 60 seconds. The total number of words was considered for scoring.

2.2.2 | Letter fluency task

This task included three letters of /a/, /f/, and /s/. After hearing each letter, the respondent was requested to write quickly as many words as possible initiated with each of these letters in 60 seconds. As mentioned above, the total number of words was considered for scoring.

2.2.3 | EEG recording

The EEG signals were recorded by Mitsar amplifier (Mitsar, Russia) with Ag/AgCl electrodes. Impedance of the electrodes was kept under 5 kΩ. The montage was linked-ear. The waves were recorded in 19 channels using the international 10-20 system. The sampling rate was 250 Hz and a 40 Hz low-pass filter was applied. Three-minute EEG signals were recorded for each condition. To reject artifacts, signals were inspected visually. Finally, at least 40 two seconds artifact-free epochs were extracted. Absolute power of delta (1-3.5 Hz), theta (4-7.5 Hz), alpha (8-12 Hz) and beta (12.5-30) was calculated based on FFT by Neuroguide software. The number of FFT point was 250, and the overlapping ratio was 0.5.[32] Regions of interest for EEG recording were frontal (FP1, FP2, Fz, F3, F4, F7, F8), parietal (Cz, C3, C4, Pz, P3, P4), and temporal (T3, T4, T5, T6).

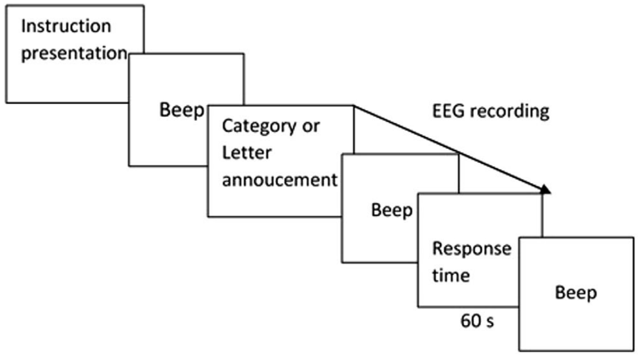

FIGURE 1 Schematic illustration of the task procedure. Participants were required to write as many words belonging to the given categories or beginning with the given letters during 60 s. The arrow shows the time during which EEG was recorded simultaneously

2.3 | Procedure

After filling the informed consent and demographic questionnaire including the inclusion and exclusion criteria, a 3-minute recording of the participants was acquired in the resting condition while their eyes were open. Afterward, they were requested to sit comfortably in front of a monitor and focus on it. Prior to each recording, the instructions were provided according to manual of VF test. The following instructions were given: A letter/a category will be presented to you, then you have a 60-second time to produce as many words beginning with that letter/belonging to that category as you can within the given time. Remember that proper nouns such as people's, city, and country names were not acceptable. In addition, same words with different suffixes must be avoided.[33] So, each trial will be started with a beep sound. Then the letter/ category will be presented. When you heard the second beep sound, you should start generating words. The third beep means your time is up (Figure 1). For familiarization purpose prior to experimental testing, an auditory letter or category was presented. The respondents were given 60 seconds to utter words then muscle activity artifacts were corrected by ICA. As speech muscle activity is severely individual-specific, ICA was not successful in correcting the EMG noise; therefore, response mode was changed to written word recall. Artifacts were rejected visually. Given that three cases (ie, animals, fruits, and clothes for CVF and /f/, /a/, and /s/ for LVF) were considered for each subtest of the verbal fluency test, a 3-minute recording was made. These two verbal fluency tasks were presented in a counterbalanced manner.

3 | RESULTS

First, normality of data distribution was checked by the Wilks-Shapirov test, then a repeated measures ANOVA test was used. The three conditions (rest, LVF, CVF), four frequency bands (Delta, Theta, Alpha, and Beta), three lobes (Frontal, Temporal, Parietal), and two sides (Left, Right) were assumed as within-subject variables. As the sphericity assumption was violated, Greenhouse-Geisser correction was applied. It was assumed that any significant interaction of various variables with condition could indicate task effect on EEG characteristics.

Result showed the statistically significant interaction of condition × lobe [$F(2.8, 13.46) = 7.99$, $P < .001$], condition × frequency [$F(3.5, 78) = 11.71$, $P < .001$], the condition × lobe ×frequency [$F(5.4, 119.2) = 8.7$, $P < .001$], condition × side [$F(1.94, 42.84) = 4.99$, $P = .012$], condition × lobe × side [$F(2.5, 56) = 5.18$, $P = .005$], condition × frequency × side [$F(3.65, 80.40) = 38.25$, $P < .001$], and condition × lobe × frequency × side [$F(5.78, 127) = 34.9$, $P < .001$]. Post hoc test for each lobe was run to compare the absolute power mean of each frequency band for the conditions.

The results indicated that the difference among the conditions (rest, LVF, CVF), frequency, and side was statistically significant for frontal and parietal but not for temporal lobes ($P < .05$). Based on post hoc analysis, mean difference of the absolute power of frequency bands (transformed in log) for frontal, parietal, and temporal lobes is presented in Figures 2-4.

Absolute power of the different frequency bands (delta, theta, alpha, and beta) in three conditions (Rest, CVF, and LVF) is presented in Figure 5.

4 | DISCUSSION

The present study aimed to assess brain electrical activation during verbal fluency tasks in different frequency bands. The results showed increased delta in the right frontal lobe for both LVF and CVF tasks, compared with the rest condition. Furthermore, there was an increase in delta activity in right parietal lobe during LVF and CVF, compared with the rest condition. In addition, both tasks showed higher theta in the right and left parietal and temporal lobe as well as right frontal lobe, compared with the rest condition.

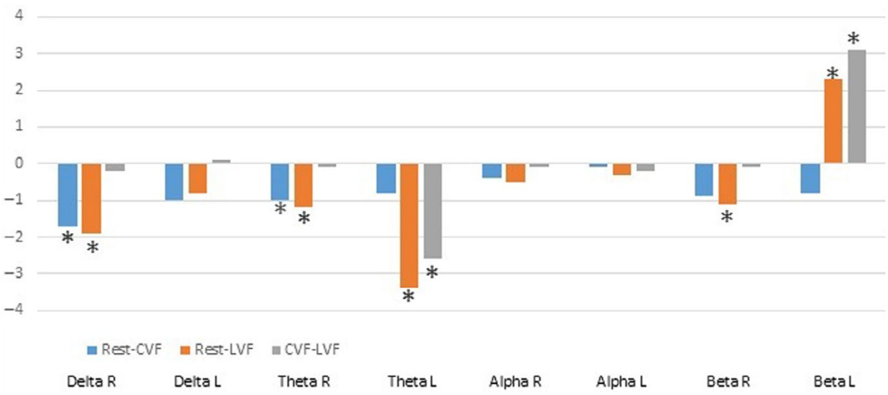

FIGURE 2 Mean difference of frequency bands (delta, theta, alpha, and beta) of frontal lobe in three conditions (Rest, CVF, and LVF). R: right, L: left, CVF: category verbal fluency, LVF: letter verbal fluency. *Significant difference at .05

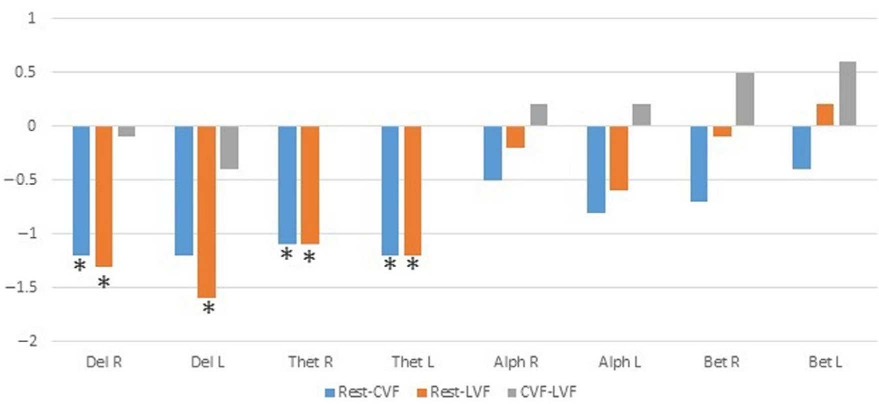

FIGURE 3 Mean difference of frequency bands (delta, theta, alpha, and beta) of parietal lobe in three conditions (Rest, CVF, and LVF). R: right, L: left, CVF: category verbal fluency, LVF: letter verbal fluency. * Significant difference at .05

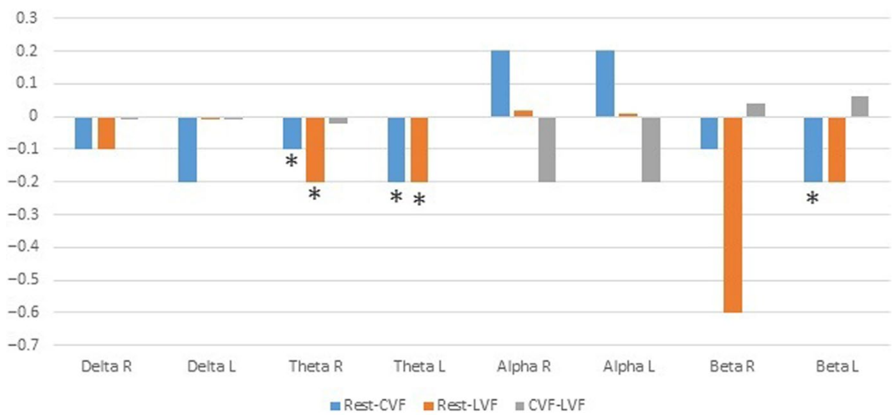

FIGURE 4 Mean difference of frequency bands (delta, theta, alpha, and beta) of temporal lobe in three conditions (Rest, CVF, and LVF). R: right, L: left, CVF: category verbal fluency, LVF: letter verbal fluency. *Significant difference at .05

Compared to rest condition, during CVF, increased beta was observed in the left temporal lobe. However, during LVF, higher theta in the left frontal lobe, increased beta in the right frontal lobe, and decreased beta in left frontal lobe and increased delta in left parietal lobe were observed. Furthermore, increased theta and decreased beta in the left frontal lobe were observed for LVF, compared to CVF. In other words, searching the words by phonological entries is associated with decreased beta and increased theta bands in the left frontal lobe. These changes are not necessary for semantic word retrieval strategy.

4.1 | Delta band changes

Functional imaging studies revealed that a crucial factor of successful performance in verbal fluency tasks is the inhibition of similar words recurrently coming to mind. This might explain the observed activation of delta in the right frontal region involved in response inhibition, as previous studies showed that delta measures were increased during response inhibition.[34–37] Furthermore, the right frontal activity is related to retrieval success in the case of detailed recollection.[38]

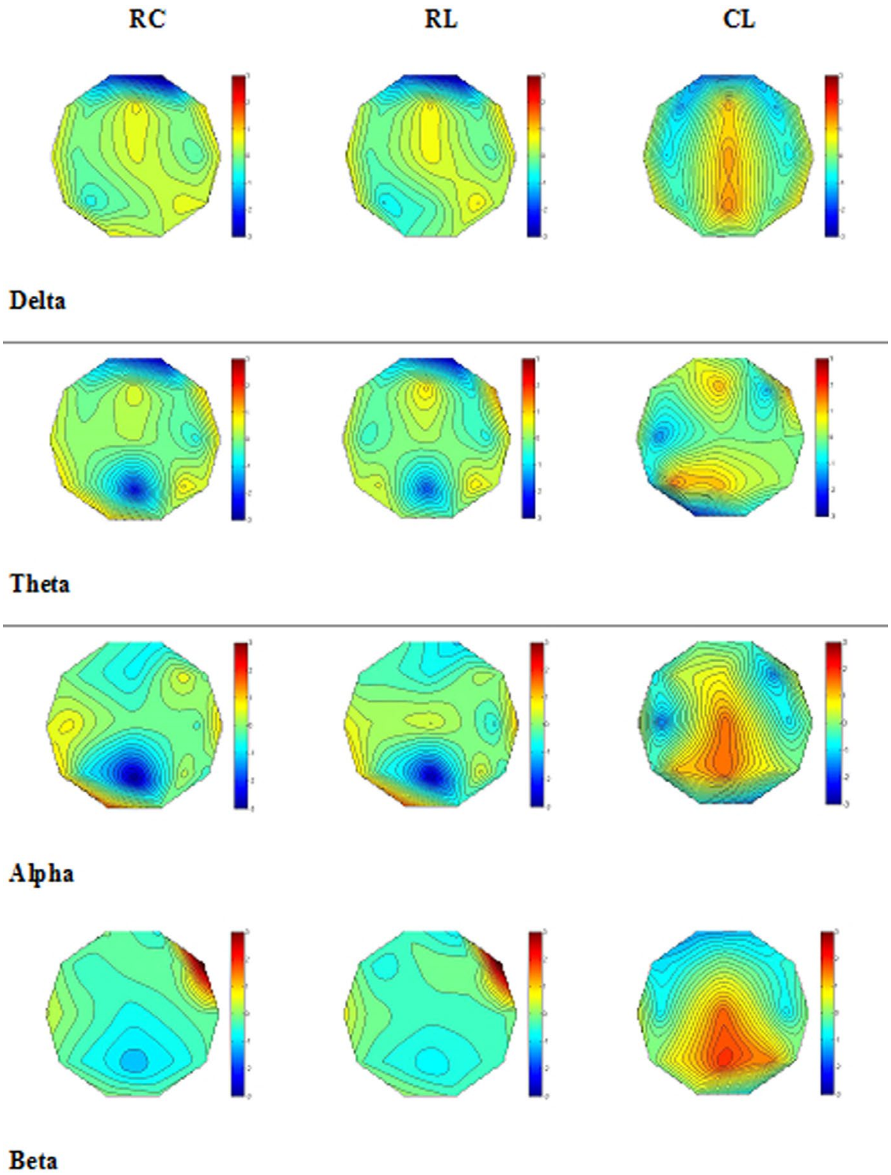

FIGURE 5 Absolute power of the signal in three conditions. (R. Rest, C. Category Verbal Fluency, L. Letter Verbal Fluency). Absolute power is presented in different frequency bands (delta, theta, alpha, and beta). For easy comparison, the values were transformed into *z*-scores

In both types of fluency tasks, the participants are required to inhibit the irrelevant stimuli, either the words of unrelated categories or words with a different initial letter; therefore, the change in the delta wave was observed in both right and left frontal and parietal lobes. Different lines of evidence suggested that increased delta EEG power is a reliable and quantitative index of neural inhibition, for example, the study on schizophrenic patients indicated that delta activity increases in frontal and parietal regions which is associated with the inhibition of interferences during task performance.[35,39] Furthermore, it was suggested that an increase in delta activity might be related to an increase in respondents' internal concentration.[35,40,41] Considering the present study, testing situation requires concentration and attentiveness, the result of which is the change in delta band in both hemispheres.

Delta frequencies in frontal areas, while doing mental tasks, are linked to "functional cortical deafferentation," or "inhibition of the sensory afferences" that get in the way of internal concentration. So, while doing an attention-demanding tasks (such as retrieval of words or category members), delta that initiates from the frontal cortex might modify the activity of neural networks that are away from the left and right frontal lobes.[40]

4.2 | Theta band changes

Based on EEG studies during information retrieval, changes in delta and theta bands manifested higher order control processes of memory.[42] Theta has been assumed to organize information into and out of the hippocampus.[43,44] During retrieval, neural oscillations in the theta band have been increased[22,45–50] in the medial temporal lobe (MTL), prefrontal cortex (PFC),[22,51] and right parieto-temporal area.[52] Moreover, activation of theta in the right frontal region is related to inhibition.[35,36] Brickman et al[14] have also reported positive relations between animal naming task and frontal and temporal theta power, while no meaningful relationship was found between theta power and LVF performance. It may suggest that theta is specifically responsible for semantic-related processing in language.[53]

4.3 | Beta band changes

In the present study, beta changes in left frontal and temporal lobes for LVF and CVF are twofold. Previous studies show that beta changes can be related to motor processes in action words, attention, inhibition, memory, and binding mechanisms during language processing.[54] Egner and Gruzelier[55] targeted lower beta frequencies in a neurofeedback training for healthy individuals. By training participants how to precisely increase low beta power, they could successfully manipulate their attentional capacity.[55] The researchers reported that enhanced beta power and beta range frequencies (12-30 Hz) are engaged in semantic retrieval.[46,56–59]

Beta oscillations were also reported to influence inhibitory processes.[60,61] Although these studies commonly linked beta oscillations with inhibition while processing a stimulus, the inhibitory processes activated before the beginning of a stimulus might prepare the memory system to integrate the new input through the inhibition of competing memory traces. In line with this idea, Waldhauser et al[60] presented evidence for the impact of low beta oscillations on the suppression of competing memories at the time of episodic memory retrieval. Similarly, Jensen and Mazaheri[61] reported that high alpha/low beta activity controls information processing through the inhibition of the task-irrelevant regions in the brain.[60,61] Finally, some other studies[42,54,59] showed that beta oscillations, either its increase or decrease, are related to memory processes.

Consistent with the previous studies, language production is strongly associated with beta decrease in premotor and motor regions during language tasks requiring motoric components even motor imagery.[62,63] It seems that beta properly indicates mental activation of motor-related systems while processing language. For example, during letter fluency tasks, strong left hemispheric decrease of 15-25 Hz was observed.[54] This beta band decrease over left frontal sites may be related to the pronunciation of words as Klimesch et al[49] study on dyslexic participants and healthy controls revealed. On the other hand, beta increase at left temporo-parietal areas reflects semantic binding during word processing.[49,54]

According to these findings, it can be assumed that beta changes might depend on phonological or semantic demand of word finding task. Moreover, the areas in which beta frequency band changes are related to task features, as well.[64]

Consistent with the finding of the present study on the contribution of left frontal lobe to letter fluency tasks, a study on normal subjects doing the tasks that were supposed to be mediated by the left frontal region showed that this region was more involved in letter fluency than semantic fluency tasks.[65] Furthermore, study on the role of frontal vs. temporal cortex in verbal fluency tasks revealed that letter fluency is primarily mediated by left frontal cortex since frontal cortex is involved in the formation of basic word forms and strategic word retrieval.[6] This viewpoint is further reinforced by functional imaging studies that revealed constant activation during verbal fluency tasks in the left frontal cortex corresponding to Broca's area in the dorsolateral prefrontal cortex, premotor cortex, and cerebellum.[66–68]

The present study provides evidence to support the contribution of the right hemisphere to language and confirm that language has a much wider distribution in brain than it was previously acknowledged (ie, language processing is commonly left dominated).[69] It was asserted that right hemisphere is equipped with all language information in parallel with the left hemisphere; however, it performs its own unique computations which might lead to different outputs.[39,70] Evidence showed that performing verbal fluency and other complex tasks could be dependent on a delicate equilibrium between the attempts of the right hemisphere to explore and the tendencies of the left hemisphere to conserve[70] which might further support the bilateral activation of both hemispheres while performing verbal frequency tasks.

What can be further speculated about the right hemisphere activation, especially the frontal lobe, in the verbal fluency tasks is that the different involvement of right frontal lobe might reveal a "visuospatial mental imagery strategy," in which the participants create mental images of correct items (animals, fruits, and clothes in our case).[5] This strategy could be beneficial when searching our semantic memory and our repertoires of words. According to the observation that participants frequently state, they imagine themselves walking in a farm or zoo when they are requested to name as many words related to a category or a letter as possible.[6]

Written responses in this study might limit generalizing the results to the spoken response mode. As abnormal theta and delta are seen in aphasia and schizophrenia, frequency bands changes during word recall are required to be studied in these patients as well. To conduct a more precise study, it is recommended to use time-locked EEG during verbal fluency tasks in which EEG signal before each expressed word can be studied.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTION

All individuals included as authors of papers contributed substantially to the scientific process leading up to the writing of the paper. Najva Mousavi involved in conceptualization, writing the original draft preparation, and software. Mohammad Ali Nazari involved in data curation and methodology. Jalil Babapour performed visualization and investigation. Ali Jahan involved in conceptualization, writing, reviewing and editing, and supervision. All authors take final responsibility for the decision to submit for publication and have approved the final version of the paper. All authors had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. The authors are entirely responsible for the scientific content of the paper.

APPROVAL OF THE RESEARCH PROTOCOL BY AN INSTITUTIONAL REVIEWER BOARD

The study was approved by the local ethics committee based on obligations of Helsinki declaration.

INFORMED CONSENT

Written consent was obtained from all the participants following the explanation about the aim and process of the study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions because consent for all data directly associated with the results to be made available in a permanent, publicly accessible data archive, or repository was not obtained in the patient consent forms.

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