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Parallel task contexts in QoE testing. Can EEG help to understand the results?

Jan HOLUB[1]; David Pánek[2]

[1] Faculty of Electrical Engineering, Czech Technical University in Prague, Czech Republic

[2] Faculty of Physical Education and Sport, Charles University, Czech Republic

ABSTRACT

Improved intelligibility of distorted speech has been observed after a parallel psycho-motor task has been introduced. Electroencephalographic activity has been recorded and analyzed for several test situations – neutral, a plain intelligibility test, an intelligibility test with parallel aimed shooting, and an intelligibility test with parallel hit counting. Our findings indicate increased brain activity in the area of the central auditory circles, which evaluate the content of audio information during a parallel cognitive and motor task when the complex motor parallel task is considered to be primary (more important).

Keywords: Sound quality, speech intelligibility, parallel task, EEG

1. INTRODUCTION

Speech intelligibility is a measure of the clearness of speech, and subjective testing of speech intelligibility has been standardized, e.g., in (1). The application of appropriate statistical methods (2) enables statistically significant assessments of compared technologies to be made, or a reliability statement can be made when a minimum intelligibility threshold has been defined. The main issue, however, is the validity of the fundamental assumption that underlies all currently used test methods: in standardized tests, the subjects are seated in an anechoic or semi-anechoic test room and are focused on listening to the tested samples only. In many real communication scenarios, however, users perform multiple tasks in parallel (jogging, watching TV or driving a car while talking on the phone, for example).

Existing subjective test methods and related recommendations are based on the simple assumption that laboratory tests with the subjects fully concentrated on the test procedure provide the most sensitive results. In other words, it is assumed that the test samples will generate higher intelligibility scores than any real-life scenario in which users are distracted by multitasking. However, it is necessary to verify the validity of the assumption that tests based on fully-concentrated and undistracted subjects necessarily achieve the highest score.

An interesting way to bring subjective tests closer to reality while keeping them in a controlled laboratory environment is to introduce a parallel task. The test subjects are asked to perform a physically and mentally challenging secondary task while listening to and evaluating the samples. The recently approved ETSI Technical Report (3) includes state-of-the-art approaches that have been used in various published scientific experiments, and also necessary recommendations, classifications, types of subjects, and various examples of scenarios as a guide for researchers when organizing parallel task-based subjective tests.

In 2018, interesting counter-intuitive results were reported in (4) from intelligibility tests deploying a parallel task. In some situations, it is reported that the intelligibility scores were statistically significantly higher with a parallel task than without it. EEG activity monitoring has been proposed as a way to investigate why this effect was observed (5).

Electroencephalography (EEG) is a widely-used neurophysiological diagnostic method that displays electric brain activity in a defined spectrum. The main advantage of EEG is its non-invasiveness, which allows repeated and prolonged recording of brain activity during periods of

[1] holubjan@fel.cvut.cz
[2] david.panek@seznam.cz

resting and also periods of movement. It is regularly used for monitoring key indicators of the onset of fatigue, performance motivation and a range of other cognitive functions. Our study uses the EEG method in a general way, focusing in greater detail on standardized low-resolution electromagnetic tomography (sLORETA) (6), a widely-used inverse solution technique that estimates the intracranial distribution of electrical activity in the cortex based on an a priori defined head conductivity model. sLORETA estimates the sources underlying scalp EEG data in a 3-D cortical space. The spatial volume units (voxels)that are used to calculate the distribution of current densities are defined on the basis of the Talairach atlas and the corresponding digital probability brain atlas (7). sLORETA determines the current densities in a total of 6 239 voxels with a spatial resolution of 5 mm3 (6).

2. EXPERIMENTS

2.1 Experiment design

In our experiment, multiple intelligibility tests were performed, always using the same set of distorted speech samples, played out in different random orders. The initial test followed the standardized methodology, with no additional activity of the subjects. The other intelligibility tests then deployed two different parallel tasks, designed to require different amounts of mental and additional physical effort from the test subjects. The EEG activity was monitored in the steady-state situation (with closed eyes and also with open eyes), during a regular intelligibility test and two intelligibility tests deploying parallel tasks.

The selected parallel task (aiming a handgun at a moving target and shooting or, alternatively, counting the successful hits of another shooter) generates a well-defined and highly repeatable psycho-motoric load, as opposed to the purely physical tasks (e.g., a stationary bicycle) or the purely mental tasks (e.g., mathematical quizzes) described in (3). This kind of task is chosen to avoid the sensitivity of the test to the physical or mental skills inequity of the test subjects.

2.2 Methods

All tests were performed in an acoustically treated critical listening laboratory conforming to (8) – with a reverberation time of 185ms, and background noise less than 30dB SPL(A), with no fluctuations in frequency spectra. Sennheiser HD280Pro closed circumaural headphones were used for sample playout. A professional voting device was used to collect the subjects' responses.

The intelligibility tests followed the Modified Rhyme Test (MRT) methodology, as described in (1). 48 samples selected from the MRT sample list were used, and due to the limited capacity of the voting device, only five answer options were used, instead of the originally proposed six options. The samples had been recorded using the voices of two male English native narrators, using 24 recordings from each of them. The distorted samples were produced using a network simulator deploying a set of a contemporary regular and low bit-rate coder and background noise options: Pulse Code Modulation (PCM) (9) at 64kbit/s (16 reference samples) and a low bit-rate coder (Mixed-Excitation Linear Predictive enhanced - MELPe) (10), operating at 2.4kbit/s (32 samples). 16 MELPe samples (out of a total of 32) were mixed with car interior background noise at Signal-to-Noise ratio SNR=0dB. A diotic presentation level of 73dB SPL (A) was used. Further details about the structure of the sample and the way in which it was created are available in (4). For some samples, the intelligibility scores were higher with the parallel task than without the parallel task, see Tab. 1 (adapted from (4)):

Table 1 – Selected speech samples where the intelligibility was measured to be higher with a parallel task than without a parallel task, deploying over 50 respondents (after (4)):

Sample Number	Intelligibility without parallel task (%)	STD	Intelligibility with the parallel task (%)	STD
17	60	6,9	78	5,9
36	51	7,0	70	6,3
42	37	6,7	56	7,0

2.3 Test procedure

Six subjects (three female and three male) in the age range from 19 – 45 were tested. All of them were native English speakers. The experiment consisted of four phases. First, a steady-state EEG was recorded with open eyes and with closed eyes (5 minutes each). Then, regular intelligibility tests were performed with EEG activity monitored (COUNTER and SHOOTER). One session lasted approximately 12 minutes.

This experiment had four phases:

Resting EEG with closed eyes (PRE CE) and with open eyes (PRE OE)

Intelligibility test without a parallel task (WORDS)

Intelligibility test with a parallel task – one subject played the role of the 'shooter' (SHOOTER)

Intelligibility test with a parallel task – one subject played the role of the 'counter' (COUNTER)

The third and fourth phases repeated the intelligibility test (with different randomization), but with a parallel task. The parallel task deployed a professional laser shooting simulator. This part of the test was always performed by two subjects. In the third phase of the test, one of the subjects played the role of the 'shooter' while the other subject acted as the 'counter'. In the last (fourth) phase, the subjects swapped their roles ('shooter' vs. 'counter') and repeated the intelligibility test for the last time. The two subjects ('shooter' and 'counter') performed the intelligibility test in parallel. The order of phases 2, 3 and 4 was randomly generated to minimize the influence of the learning effect in the intelligibility test. Further details about the voting process and about intelligibility data acquisition are available in (4).

A professional laser shooting simulator was used for generating the parallel task. For the EEG measurements, we used the Electro-Cap, Inc. Nicolet EEG wireless 32/64 Amplifier with a telemetric 32-channel (Natus 98 Neurology, Inc. USA). The EEG data was recorded with 19 electrodes: Fp1, Fp2, F7, F3, Fz, F4, F8, T5, T3, C3, Cz, C4, T4, T6, P3, Pz, P4, O1, O2. The electrodes were localized according to the 10–20 international system [11]. The sampling frequency was set to 512 Hz, with a band-pass filter from 0.5–70 Hz, and the electrode impedance was kept below 10 kΩ.

All EEG data were subjected to editing procedures, using Neuroguide software (Neuroguide © NG-2.4.6; Applied Neuroscience Inc., St. Petersburg, Fla., USA). We used Neuroguide to select 30 seconds of artifact-free data. After transformation to the average reference, the EEG activity of at least 15 two-second epochs of artifact-free resting EEG were averaged to calculate the cross-spectra in sLORETA for six non-overlapping frequency bands: delta (1.5–6 Hz), theta (6.5–8 Hz), alpha-1 (8.5–10 Hz), alpha-2 (10.5–12 Hz), beta-1 (12.5–18 Hz), beta-2 (18.5–21 Hz), and beta-3 (21.5–30 Hz). Using the sLORETA transformation matrix, the cross spectra of each subject and for each frequency band were then transformed to sLORETA files. This resulted in the corresponding 3D cortical distribution of the electrical neuronal generators for each subject (12). The computed sLORETA image displayed the cortical neuronal oscillators in 6239 voxels, with a spatial resolution of 5 mm (6).

The localization of the differences in brain electrical activity within the groups was assessed by a voxel-by-voxel paired t-test of the sLORETA images, based on the power of the estimated electric current density, which resulted in t-statistic three-dimensional images. In the sLORETA images, cortical voxels of statistically significant differences were identified by a nonparametric approach, using a randomization strategy that determined the critical probability threshold values for an actually observed statistical item, with corrections for multiple testing (13).

In each group, we compared the difference on a level of significance of $p \leq 0{,}05$, under the following circumstances:

'Shooter' versus resting EEG with open eyes –SHOOTER vs. PRE OE

'Counter' versus resting EEG with open eyes – COUNTER vs. PRE OE

'Counter' versus the intelligibility test, without a parallel task – COUNTER vs. WORDS

3. RESULTS

3.1 Alpha activity pre-test

All participants generated alpha activity during resting EEG with closed eyes, so all participants were able to produce this alpha activity when in a relaxed state.

3.2 Words vs. PRE OE

We observed statistically significant differences p≤0,05 in the delta band when comparing the intelligibility test without a parallel task (WORDS) versus the resting EEG with open eyes (PRE OE). We found increased activity in the delta band in the right dorsolateral prefrontal cortex (DLPFC), which is responsible for higher cortical functions associated with executive functions and motor planning (Fig. 1).

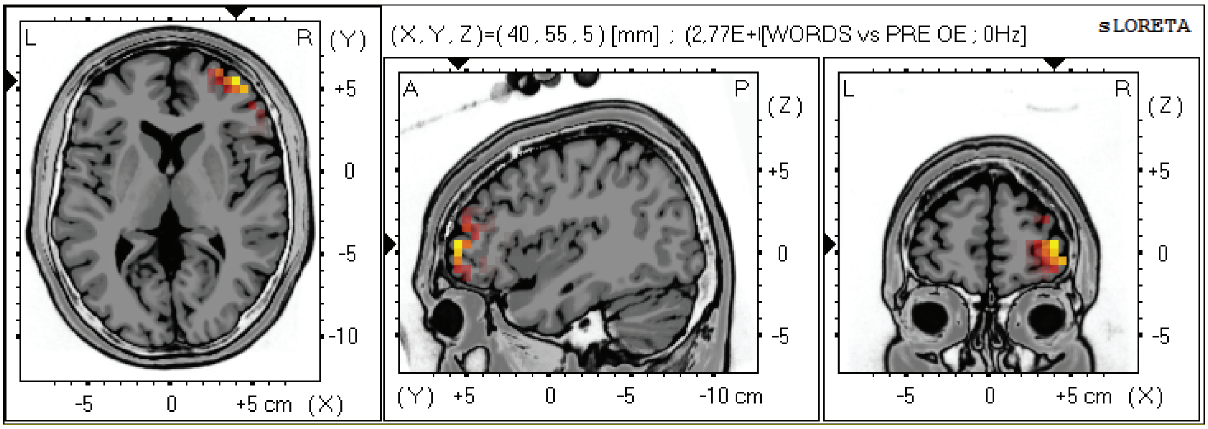

Figure 1 - Statistical non-parametric map (SnPM) of sLORETA differences in delta current density when comparing the intelligibility test without a parallel task (WORDS) versus the resting EEG with open eyes (PRE OE). Yellow and red shades indicate a significant increase in delta sources (at the 0.05 significance level after correction for multiple comparisons.) in BAs 10,11, 46 and 47 (frontal gyrus). The structural anatomy is shown in grey scale (L – left; R – right).

3.3 Shooter vs. PRE OE

When comparing the intelligibility test with the parallel task - shooter (SHOOTER) versus resting EEG with open eyes (PRE OE), we observed significant changes in the beta-2 and beta-3 band only. We found decreased activity in the beta-1 band in the posterior cingulum (BA 31), which is responsible for integrating stimuli and their emotional experience. Increased activity in beta-3 occurs in the middle-temporal lobe (BA 21), which is involved in processing complex sounds, in selective processing of text and speech, and in semantic processing (Fig 3).

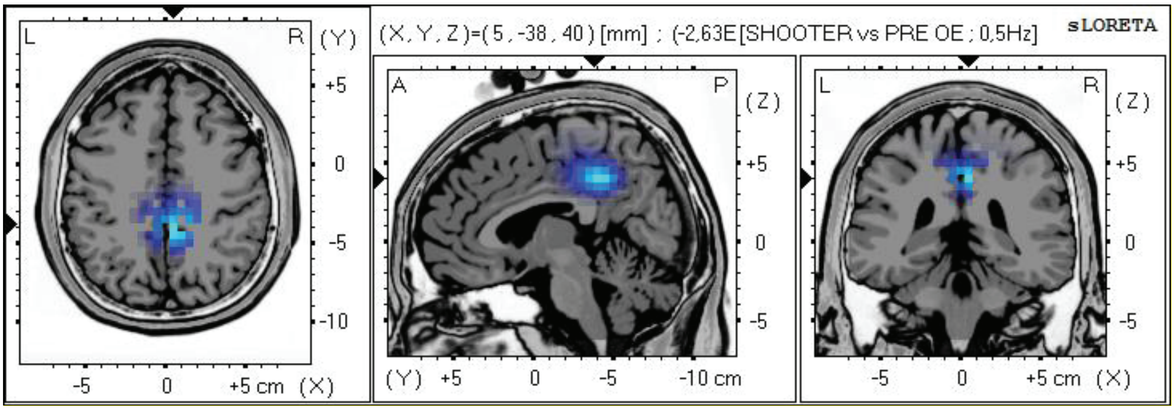

Figure 2 - Statistical non-parametric map (SnPM) of sLORETA differences in the beta-2 current density comparing the intelligibility test with the parallel task - shooter (SHOOTER) versus the resting EEG with open eyes (PRE OE). Blue shades indicate a significant decrease in beta-2 sources (at the 0.05 level of significance, after correction for multiple comparisons.) in BA 31 (gyrus cinguli posterior). The structural

anatomy is shown in grey scale (L – left; R – right).

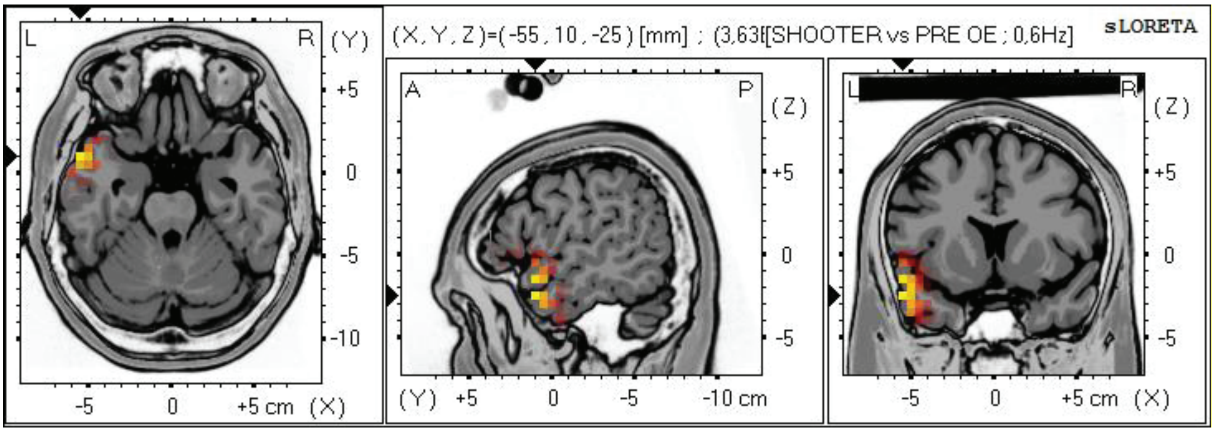

Figure 3 - Statistical non-parametric map (SnPM) of sLORETA differences in the beta-3 current density, comparing the intelligibility test with the parallel task - shooter (SHOOTER) versus resting EEG with open eyes (PRE OE). Yellow and red shades indicate a significant decrease in beta-3 sources (at the 0.05 level of significance, after correction for multiple comparisons.) in BA 21 (middle temporal gyrus). The structural anatomy is shown in grey scale (L – left; R – right).

3.4 Counter vs. PRE OE

We found statistically significant differences (level p≤0,05) in the beta-3 band when comparing the intelligibility test with the parallel task – (COUNTER) versus resting EEG with open eyes (PRE OE). The increased activity in the beta-3 band occurs in the dorsolateral prefrontal cortex (DLPFC) - BAs 10, 11, 46 and 47 on both sides, which are responsible for the execution function, and in the right temporal lobe - BA 38, corresponding to a higher level of integration of the auditory stimulus, and to semantic processing, and it participates in speech processing.

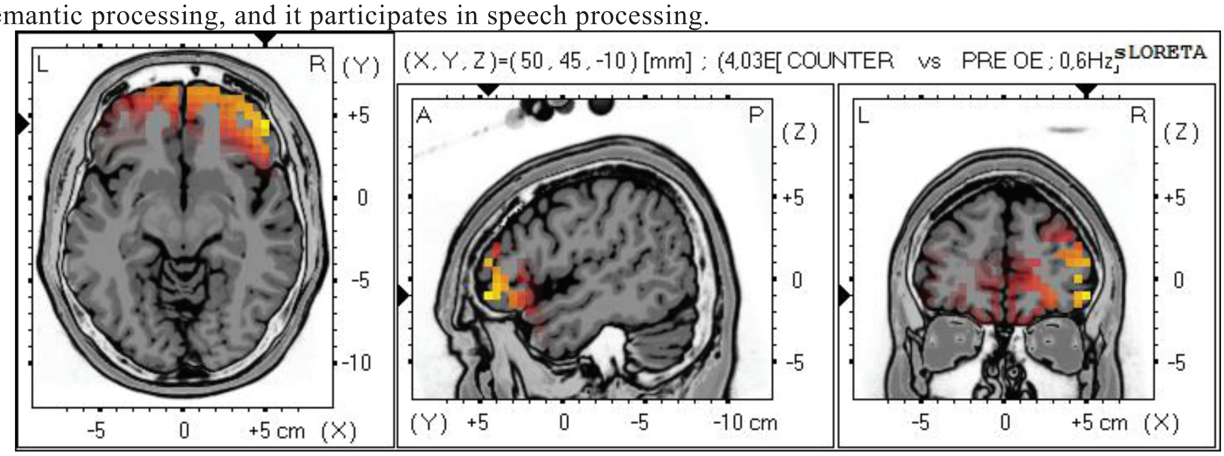

Figure 4 - Statistical non-parametric map (SnPM) of sLORETA differences in the beta-3 current density, when comparing the intelligibility test with the parallel task – counter (CALCULATOR) versus resting EEG with open eyes (PRE OE). Yellow and red shades indicate a significant decrease in beta-3 sources (at the 0.05 level of significance, after correction for multiple comparisons.) in BAs 10, 11, 46 and 47 (frontal gyrus) and BA 38 (temporal gyrus). The structural anatomy is shown in grey scale (L – left; R – right).

3.5 Counter vs. Words

When comparing the intelligibility test with the parallel task – counter (COUNTER) versus the intelligibility test without a parallel task (WORDS), we found statistically significant differences in the beta-3 current density in the left dorsolateral prefrontal cortex - BAs 10, 11, 46 and 47, corresponding with the higher execution functions.

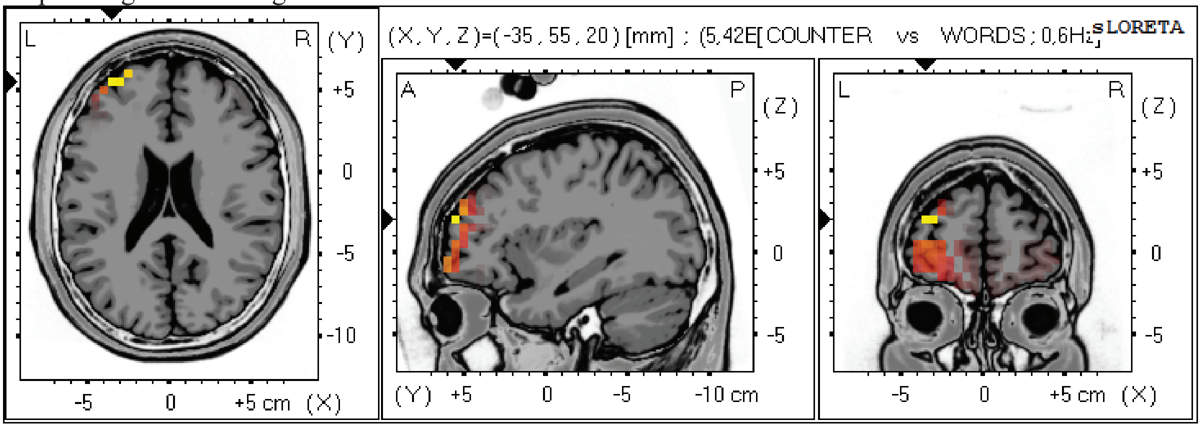

Figure 5 - Statistical non-parametric map (SnPM) of sLORETA differences in the beta-3 current density, when comparing the intelligibility test with a parallel task – counter (COUNTER) versus the intelligibility test without a parallel task (WORDS). Yellow and red shades indicate a significant increase in beta-3 sources (at the 0.05 level of significance, after correction for multiple comparisons) in BAs 10, 11, 46 and 47 (frontal gyrus). The structural anatomy is shown in grey scale (L – left; R – right).

4. DISCUSSION

Central auditory processing follows two major pathways, both originating in the primary auditory cortex (temporal cortex BAs 41, 42): Pathway 1. the ventral auditory stream from the posterior middle and inferior temporal gyrus to the anterior, middle temporal gyrus (MTG) for identifying auditory objects, including speech. This is called the WHAT system for sounds recognition. Pathway 2. the dorsal auditory stream into the superior temporal cortex and the parietal cortex for analyzing spatial aspects of sounds, including motion in space. This is called the WHERE system for auditory spatial analysis (14,15,16,17).

A difference is found between the roles of simple intelligibility test (WORDS) and counting while observing a shooter (COUNTER). During the plain intelligibility test (WORDS), we observe activity only in the right dorsolateral prefrontal cortex (DLPFC). However, during the intelligibility test performed together with watching the shooter (COUNTER), we can observe activity above both frontal lobes, with dominance on the right and in the temporal area of the right temporal lobe BA 38, which indicates activity of the ventral/WHAT auditory circle (14,17). The finding of increased activity in the temporal area can correlate with the increased action in the region for processing the meaning of the perceived word. The heightened activity above the frontal lobes can be associated with the so-called behavior inhibitory system (BIS), which indicates a rather negative reaction to the current situation and the behavior activation system (BAS), which is activated during a positive emotional reaction to the ongoing situation (19,18). During the plain intelligibility test (WORDS), dominance above the right frontal lobes is observed, which can indicate BIS activity, probably indicating negative subject attitude during this test. During the role COUNTER, conversely, there is increased activity over the right frontal lobe, which matches BAS activation with a positive emotional response, suggesting that the subject's attention may have been taken by the shooter. In general, activity in the DLPFC area is connected with executory functions, motorical scheduling, and learning (20).

During the role of SHOOTER, we observe decreased activity in the dorsal cingular cortex BA 31. Together with the anterior cingular cortex, BA 31 has a strong reciprocal connection with the lateral prefrontal cortex, and through this connection, they partake in executory functions of the working memory and motoric planning (21). The dorsal singular cortex participates in spatial navigation and in processing surrounding scenes (22, 23). Depressed activity during this experiment may indicate a certain attenuation of motoric movement perception and reduced emotional reactions. The finding of raised activity for SHOOTER in the area of the middle temporal lobe BA 21, correlates with the increased activity in the ventral/what auditory circle and is in response to raised analyzing processes of the auditory stimulus (14,17).

Although we did not capture activity in the primary auditory zones BAs 41, 42 of the temporal lobe, activity in COUNTER and in SHOOTER was observed in the ventral/WHAT auditory circle and in associated areas of the prefrontal lobe that integrate those primary acoustical stimuli into an understandable form, enabling it to be perceived and evaluated in a complex manner.

Although alpha activity was measured during resting EEG in all participants, it was not registered during the experiment itself. This finding is probably connected with the major cerebral activity that is needed for processing acoustical information together with an accompanying activity. Consequently, if we want to pass on some information through an acoustic stimulus, it can be processed more intensely if the listener simultaneously performs a parallel activity.

The results indicate that the intelligibility results for plain listening during a standard laboratory intelligibility test can be outperformed by a test procedure that is enhanced by the introduction of a parallel task. The EEG measurements indicated that the higher auditory and cognitive brain functions are enhanced during parallel tasks that engage the subject in the test procedure and/or during parallel tasks that reduce the "internal dialogue" of the subjects. Internal dialogue occurs involuntarily during regular laboratory intelligibility tests not involving any parallel task, and probably cannot be controlled consciously by ordinary test subjects. These counter-intuitive results imply the need for substantial changes not only in subjective intelligibility testing methodology but also in perception stimulation in highly demanding professional scenarios, in rehabilitation and in education.

5. CONCLUSIONS

EEG activity has been recorded and analyzed for several test situations. Distinct differences in brain processing of auditory content were found among three groups of subjects, referred to as WORDS, COUNTER, and SHOOTER. The listening-only group (WORDS) shows changes only in the real prefrontal cortex area, indicating increased activity in the circles that participate in the comprehensive evaluation of all input information. The listening and observing group (COUNTER) also has increased activity in these areas of the prefrontal lobe, but on both sides of it, and, at the same time, there is increased activity in the left temporal lobe, corresponding to zones of complex processing of the auditory stimulus. This area is involved in central auditory circuits that evaluate the content of the acoustic stimulus. Increased activity in these areas is also found in the listening and shooting group (SHOOTER). At the same time, however, activity in the limbic area is reduced, which can indicate reduced emotional manifestations and efficiency of the psycho-motoric parallel task. These findings indicate increased brain activity in the area of the central auditory circles that are evaluating the content of audio information during parallel cognitive and motor tasks when a complex motoric parallel task is considered to be primary (more important).

The results of this experiment show that the brain analysis of the content of the stimuli may be higher during parallel operation. This effect is reflected primarily in content-rich auditory information that requires deeper analysis.

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