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Data Descriptor

Electroencephalograms during Mental Arithmetic Task Performance

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Abstract: This work has been carried out to support the investigation of the electroencephalogram (EEG) Fourier power spectral, coherence, and detrended fluctuation characteristics during performance of mental tasks. To this aim, the presented dataset contains International 10/20 system EEG recordings from subjects under mental cognitive workload (performing mental serial subtraction) and the corresponding reference background EEGs. Based on the subtraction task performance (number of subtractions and accuracy of the result), the subjects were divided into good counters and bad counters (for whom the mental task required excessive efforts). The data was recorded from 36 healthy volunteers of matched age, all of whom are students of Educational and Scientific Centre "Institute of Biology and Medicine", National Taras Shevchenko University of Kyiv (Ukraine); the recordings are available through Physiobank platform. The dataset can be used by the neuroscience research community studying brain dynamics during cognitive workload.

Dataset: Dataset is available on Physiobank: https://physionet.org/physiobank/database/eegmat/

Dataset License: the dataset is available under ODC Public Domain Dedication and Licence (PDDL)

Keywords: EEG; mental arithmetic; cognitive workload

1. Summary

The study of human cognitive activity has attracted a lot of interest from researchers of different domains, from biophysics and connectomics to system analysis and digital signal processing. One of the main fields is the study of brain activity dynamics during emotional states that are integrated with cognitive processes. Many theoretical and practical works have been published over the last decades about the relationships between cognitive phenomena and activity of brain structures [1], the "global workspace" theory of brain functioning during emotions and mental activity [2], dynamical properties of cortical areas and their coordination [3], and brain networks interaction during creative cognition and artistic performance [4]. Also, excellent recent textbooks [5,6] on cognitive neurophysiology, neuropsychology, and neuroscience are available to dive deep in the domain, as well as review papers [7,8] describing recent advancements and future directions in brain–computer interface algorithms and technologies used to measure and quantify the mental and emotional states in real settings. The activation of functional and anatomical brain areas during cognitive activity has mainly been studied by the standard techniques of spectral [9,10] and coherence [11,12] analysis, which are well-established and powerful tools used to reveal the important characteristics of brain functioning. To advance this research direction by exploring the new possibilities of nonlinear signal processing techniques, a characterization of brain activity during cognitive activity using these new indicators must first be performed.

The aim of the present study is to collect the electrical activity of the brain using electroencephalogram (EEG) data from subjects performing a cognitive workload task. During the study, the subjects were involved in intense cognitive activity while performing mental calculations (serial subtractions). For comparison, the background EEG was recorded from each subject. The primary aim for collecting this dataset is to conduct detrended fluctuation analysis [13–15] of the EEG during cognitive activity and to compare the result to the data provided by conventional methods, such as Fourier power spectral density mapping and coherence. It can also be utilized for studying the time-scale characteristics of the involvement of different brain areas in cognition processes and nonlinear characteristics of brain dynamics.

As a result of this work, EEG recordings from 36 subjects have been registered and cleared of artifacts, and have been made available to the cognitive neuroscience research community.

2. Data Description

2.1. EEG Recording

The EEGs were recorded using Neurocom monopolar EEG 23-channel system (Ukraine, XAI-MEDICA). Silver/silver chloride electrodes were placed on the scalp at symmetrical anterior frontal (Fp1, Fp2), frontal (F3, F4, Fz, F7, F8), central (C3, C4, Cz) parietal (P3, P4, Pz), occipital (O1, O2), and temporal (T3, T4, T5, T6) recording sites according to the International 10/20 scheme. All electrodes were referenced to the interconnected ear reference electrodes. The inter-electrode impedance was below 5 kΩ. The sample rate was 500 Hz per channel. A high-pass filter with 0.5 Hz cut-off frequency, low-pass filter with 45 Hz cut-off frequency and a power line notch filter (50 Hz) were used; the time constant of the amplification tract was 0.3 s.

2.2. EEG Selection

Every recording includes separate artifact-free EEG segments of 180 s for resting state and 60 s for mental counting. Based on EEG visual inspection by a qualified electroneurophysiologist, 30 of the 66 initial participants were excluded from the database due to poor EEG quality (excessive number of oculographic and myographic artifacts), so the final sample size is 36 subjects.

2.3. Characteristics of Participating Subjects

In Table 1, the data about the participating subjects is summarized. Females are marked with "F", males are marked with "M". "Number of subtractions" is the difference between the initial 4-digit number and the subtraction result, divided by the subtrahend. Note that if the calculation was inaccurate for a particular subject, the corresponding value is not an integer. "Count quality" is the ranking we determined based on the number of subtractions: group "B" and "G" (see description of groups in 3.3).

Table 1. Subjects and population data.

Name	Age	Gender	Number of Subtractions	Count Quality
Subject0	21	F	9.7	B
Subject1	18	F	29.35	G
Subject2	19	F	12.88	G
Subject3	17	F	31	G
Subject4	17	F	8.6	B
Subject5	16	F	20.71	G
Subject6	18	M	4.35	B
Subject7	18	F	13.38	G
Subject8	26	M	18.24	G
Subject9	16	F	7	B
Subject10	17	F	1	B
Subject11	18	F	26	G
Subject12	17	F	26.36	G
Subject13	24	M	34	G
Subject14	17	F	9	B
Subject15	17	F	22.18	G
Subject16	17	F	11.59	G
Subject17	17	F	28.7	G
Subject18	17	F	20	G
Subject19	22	M	7.06	B
Subject20	17	F	15.41	G
Subject22	19	F	4.47	B
Subject21	20	F	1	B
Subject23	16	F	27.47	G
Subject24	17	M	14.76	G
Subject25	17	M	30.53	G
Subject26	17	F	13.59	G
Subject27	19	F	34.59	G
Subject28	19	F	27	G
Subject29	19	M	16.59	G
Subject30	17	M	10	B
Subject31	19	F	19.88	G
Subject32	20	F	13	G
Subject33	17	M	21.47	G
Subject34	18	F	31	G
Subject35	17	F	12.18	G

2.4. Dataset Format Description

The dataset is formatted according to BIDS standard (https://bids.neuroimaging.io/bids_spec.pdf) [16]. In the file "participants.tsv", the "group" column provides info which subjects correspond to which group (B—Group "B", G—Group "G"). Additionally, file "participants.tsv" provides basic information about each subject (gender, age, number of subtractions, year of recording). A detailed description of each column name can be found in the "participants.json" file.

The data files with the EEG recordings are provided in EDF (European Data Format) format. Each folder contains two recording files per subject and additional metadata files, required by BIDS standard:

- "sub-<participant_label>_task-<task_label>_channels.tsv" file provides the general information about the EEG channels (name, filters used, sampling frequency),
- "sub-<participant_label>_task-<task_label>_eeg.edf" file contains the raw EEG data,
- "sub-<participant_label>_task-<task_label>_eeg.json" file contains metadata for recording file,
- "sub-<participant_label>_task-<task_label>_events.tsv" file provides the info about the recording events.

3. Methods

3.1. Experiment Design

The dataset was collected to investigate EEG correlates of mental activity during an intensive cognitive task (mental arithmetic task—serial subtraction). This model of research is quite common in the study of the mechanisms of human cognitive activity [17,18].

Arithmetic tasks in this study involved the serial subtraction of two numbers. Each trial started with the oral communication of the 4-digit (minuend) and 2-digit (subtrahend) numbers (e.g., 4753 and 17, 3141 and 42, etc.). Mental arithmetic performance is considered as a standardized stress-inducing experimental protocol [19,20]. Serial subtraction during 15 min is considered to be a psychosocial stress [21]. In this way, our study design required intensive cognitive activity from the subjects. Intensive mental load is accompanied by a change in the emotional background when the subject makes additional effort to resolve tasks, so one can talk about evoked emotions in this case.

During EEG recording, the participants sat in a dark soundproof chamber, comfortably reclined in an armchair. Prior to the experiment, participants were instructed to try to relax during the rest state and were informed about the arithmetic task—participants were asked to count mentally without speaking or using finger movements, accurately and quickly, in the rhythm they had determined. After 3 min of adaptation to experimental conditions, EEG registration of the rest state with closed eyes was made (over the next 3 min). Then the participants performed a mental arithmetic task—serial subtraction—for 4 min. The course of the experiment is illustrated in Figure 1. The two bounding boxes represent the data available in the dataset in two separate recording files.

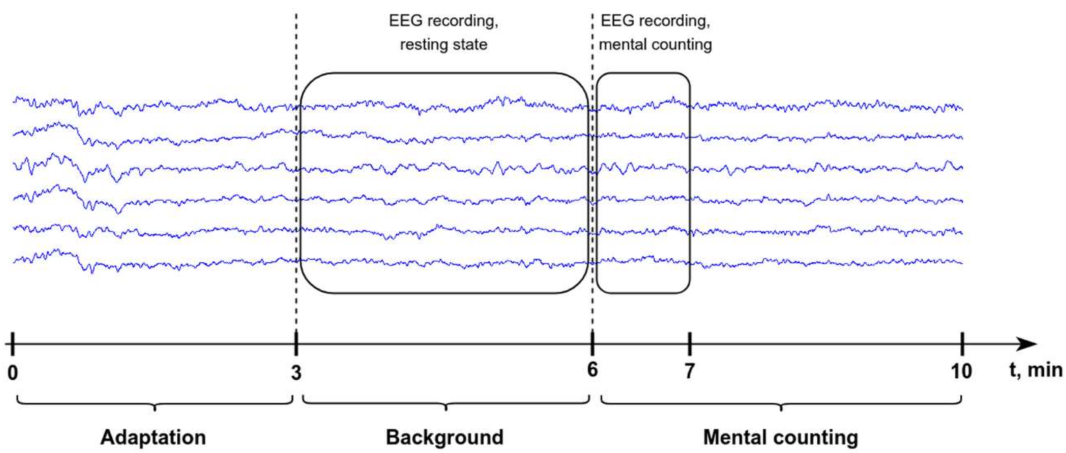

Figure 1. Organization of EEG data collection during the experiment. Bounding boxes depict the two EEG recordings stored in the database.

In this study, we collected and stored in the database EEG recordings during the last three minutes of the rest period and the first minute of the mental arithmetic performance. These periods were selected since the task performance strategy is being formed simultaneously as the task is executed, and the emotional state of the participants is changing considerably due to intellectual overload. Participants were interviewed about their strategies and experience after the experiment.

3.2. Participants

The study was approved by the Bioethics Commission of Educational and Scientific Centre "Institute of Biology and Medicine", Taras Shevchenko National University of Kyiv (Conclusion from 15 August 2018, project title "Detrended fluctuation analysis of activation re-arrangement in EEG dynamics during cognitive workload"). Each subject signed written informed consent in accordance with the World Medical Association (WMA) declaration of Helsinki of 1975 (http://www.wma.net/

en/30publications/10policies/b3/), revised in 2008, the Declaration of Principles on Tolerance (28th session of the General Conference of UNESCO, Paris, 16 November 1995), the Convention for the protection of Human Rights and Dignity of the Human Being with regard to the Application of Biology and Medicine: Convention on Human Rights and Biomedicine (Oviedo, 4 April 1997). All volunteers participated in the study for course credits.

In total, 66 healthy right-handed volunteers (47 women and 19 men) were initially involved in the study. All participants are 1st–3rd year students of the Taras Shevchenko National University of Kyiv (Educational and Scientific Centre "Institute of Biology and Medicine" and Faculty of Psychology) aged 18 to 26 years (M_{age} = 18.6 years, standard deviation (SD) = 0.87 years). The participants were eligible to enroll in the study if they had normal or corrected-to-normal visual acuity, normal color vision, and had no clinical manifestations of mental or cognitive impairment or verbal or non-verbal learning disabilities. Exclusion criteria were the use of psychoactive medication, drug or alcohol addiction, and psychiatric or neurological complaints.

3.3. Good/Bad Counters Selection

After the completion of the arithmetic task execution, the subject reported the result of the subtraction. The number of operations completed during 4 min and correctness was computed for each participant. For each participant, a mental arithmetic score was obtained by subtracting the last number reached from the initial 4-digit number. The task performance was considered accurate if the score was an exact multiple of a corresponding 2-digit subtrahend.

We had compared the mentally calculated subtraction across subjects and concluded that the participant had successfully engaged in the task if their reported result did not differ by more than 20% from the correct value. A comparable approach in assessing the quality of the task was applied in a similar study [22].

One of our aims was to assess the ability of participants to accomplish the arithmetic task. In this study, we investigated how brain activation changes based on individual task difficulty. This issue has been left unexplored by other researchers. The increase in the rate of presentation of numbers is used to investigate the task difficulty [23]. Individual task difficulty for participants can be assessed by the number of operations performed in unit time and by the characteristics of proposed numbers. In this work, to identify the EEG features associated with the task difficulty for the participants, we used the variation series (ranked series) of behavior data as the basis of the grouping. Based on the number of arithmetic operations per minute, we divided the sample (36 subjects) into two groups: the proposed task was a difficult task for one group of participants (group "B", 12 subjects, mean number of operations = 7, SD = 3,6), whereas the second group managed the task without difficulty (group "G", 24 subjects, mean number of operations = 21, SD = 7,4). Groups "B" and "G" are marked in Table 1.

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