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AUDIO-VISUAL INDUCED MENTAL WORKLOAD: RESEARCH METHODOLOGY WITH DISRUPTIVE SOUNDSCAPES AND ELECTROENCEPHALOGRAPHY

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ABSTRACT

Attention is a cognitive function necessary at work. Attention needs to be continuously controlled by the employee to reach concentration. The number of disruptive sound sources should be lowered to maintain concentration. Whenever work characteristics does not allow additional mental load might be necessary to execute a task. Thus, it is valuable to understand the neuronal dynamics underlying the processing of irrelevant sounds during cognitive tasks.
In our experiment, we will present cognitive tasks (n-back and Stroop) with and without synthetical produced occupational noise. The digitally produced noise represents a realistic soundscape. Synthetic auditory soundscapes are designed based on mobile work scenario. We register the electroencephalogram (EEG) as well as the perceived workload using the NASA-TLX and Weinstein's Noise Sensitivity Scale. We primarily address the question, of whether neuronal correlates are sensitive to fine-grained modulations of workload during audio-visual work tasks. Thus, we aim to determine whether it is possible to identify EEG parameters related to mental workload induced by cognitive tasks and the acoustic environment. Knowledge of biomarkers contributes to the ergonomic design of future workplaces.
Keywords: *EEG, noise, mental load, synthetic soundscapes, annoyance*

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1. INTRODUCTION

1.1 Mental activities and cognition at work

Many work tasks involve the mental transformation of information that are perceived, processed, and finally, saved in computer systems. Concentration on the perception, the active mental representation, and the conversion of different information in the memory play a fundamental role when it comes to effective task fulfillment at the workplace [1]. Such mental tasks are vulnerable to irrelevant auditory information, such as noise. Noisy work environments lower the acoustic ergonomics that can support employees in fulfilling of their primary work task.

To foster the well-being of employees and reduce stress, the ergonomic aspects of the work environment should support the prerequisites necessary for effective information processing. To facilitate work performance and well-being, employees themselves often act autonomously and design their own workspace: E.g., placing only files relevant to the momentary work tasks in their immediate surrounding at their desk. In contrast, irrelevant files are stored in folders away and are not appearing in the visual field. Irrelevant files in the visual field could eventually distract the attention and bind the available mental resources in directing the focus from the set work goals [2]. Similarly, work-unrelated thoughts and mental processes that are distractive or emotionally charged are ignored. Triggering visual objects for such mental activities are often removed from the environment to allow a productive work environment.

The auditory attention and distractions work similarly: relevant auditory information must be separated from noise continuously [3-5]. Noise is described as the sensory information that is irrelevant to the listener and can be harmful. At work, the aspect of safety must be also considered, additionally to the relevance of auditory information. Danger of machines can be signaled by means of a sound or a warning signal. Sound must be therefore always classified as noise or signal by the listening employee.

The hearing sense is constantly exposed to auditory information stemming from different sound sources (relevant, signal, and irrelevant, noise). Some sounds and sound sources are generally informative, whereas others are temporarily or permanently irrelevant [6]. The task of hearing is not only to form a robust representation of the auditory surroundings but evaluate the importance of the sound events. This filtration process includes separating the noise from the signal and binds mental resources. The signal might be the ringing of my telephone, whereas noise is the ringing of the telephones of my colleagues. The decision process, whether a certain sound is relevant and which information it provides, binds additional mental resources besides an persisting primary work task [7], such as reading this text.

In occupational health and safety, the usage of cognitive resources based on the physical agents of the work environment is studied for understanding and recommending actions that help to improve workplace ergonomics and employees' health [8]. Here, we study the non-auditory effects that a noisy soundscape might evoke because of noise-related mental workload arising from filtering irrelevant sound sources out of the perceived sound scene [9, 10].

1.2 Work environment: noise at work

Most of the sounds that are perceived at work are not relevant to the current task. Noise at work is primarily caused by machines and social interactions from colleagues or customers (i.e., social noise). Some research has been done to estimate the workload that stems from cognitive processes in silence and in noise. The attribution of measured cognitive workload to either process is not yet sufficiently succeeded. Moreover, the neuronal substrate or the cognitive mechanism could not yet be elucidated. We want to contribute with this experiment to the growing body of evidence that there is an objective mental cost factor for working cognitive in noisy surroundings.

Traditionally, occupational health and safety concentrated on the exposure intensity (i.e., sound pressure level) and exposure time [11]. However, with the work type changing from manual to dominantly mental work in the digital work reality of the 21st century, the cognitive processes prone to auditory distraction must be assessed in greater detail.

1.3 Mental resource measurement

In this study, we are interested in the measurement of the mental workload occurring from the combination of cognitive tasks and irrelevant sounds. We aim to attribute the load to the relevant process. The estimation of this additional mental workload stemming from the auditory distraction is a challenging endeavor since it is not yet fully disentangled [12, 13]. For example, a partially unanswered question is how idiosyncratic parameters influence the capacity of mental resources available, dependent on the physical environment [14]. The individual cognitive capacity not only influences the processing of certain cognitive tasks, but also the ability to handle two tasks at the same time (dual-task paradigm: cognitive task and noise filtering). Furthermore, the personality has also an influence on the general susceptibility to unexpected or incontrollable sound sources, as they can be found at the workplace [15].

To give relevant insights into the mental workload estimation in an occupational setting, it is necessary to consider following key issues that are determining the reliability of the measured effects. Can the mental workload be quantified on a scale that is reproducible in many different occupational settings? Can a certain proportion of mental workload be attributed to the difficulty within a certain cognitive task? Can mental workload be attributed to specific mental processes? To answer these questions, we formulate the following hypotheses:

Hypothesis 1
When a cognitive task is processed in silence and noise, the perceived mental workload increases respectively under noise.

Hypothesis 2
It is possible to distinguish parameters in frequency spectrum of the EEG influenced by a silent and a noise condition during processing of a cognitive task.

Hypothesis 3

The difficulty level of a task processed during noise has an effect on the activity level measured by the EEG.

Hypothesis 4
Depending on the relevance of the auditory signal (irrelevant vs. partially relevant), the task performance and neuronal mental workload in the EEG is differently affected by a noisy environment.

2. METHODS

2.1 Mental workload: Cognitive functions at work

At work, several different cognitive functions are used at the same time to perform complex tasks. We will make use of two classical paradigms: the n-back task and the Stroop task in different environments (noise and silence) because they are fundamentally involved in many different work tasks.

2.1.1 Task 1: n-back task

The n-back task produces a continuous cognitive load related to the working memory (capacity) [16]. Working memory is a highly important part of the cognitive system that is used during everyday tasks. In the n-back task, different numbers are presented, and the subject must press a button, whenever the currently presented number equals to the number n-steps behind. The participant is instructed to report when current and the n steps back number is equal. The n-back task imposes based on this concept a certain quantity of load on the working memory. Depending on the difficulty level (0-back or 2- back) the expected task load is changing.
The activity of the working memory goes along with activities in the frontal and parietal brain regions [17]. These brain regions will be covered by the applied EEG configuration. Here, the n-back task will be presented in a block of 184 and 202 trials with a trial duration of 1700 ms. The difficulty levels that will be implemented in these two blocks are the 0-back (38 targets) and 2-back tasks (40 targets). In both difficulty levels the targeted probability is 20%. Feedback to each reaction of the subject will be given auditorily. A wrong or a missing answer will be responded with a 2000 Hz sound for a period of 50 ms. A right answer will be responded with a 1000 Hz sound for 50 ms.

2.1.2 Task 2: Stroop task

The inhibition and cognitive control that are necessary to excel the Stroop task, can be found in work tasks, as well. Theories explaining the Stroop effect highlight, among others, the capacity of selective attention that eventually triggers the differences in the reaction time. Competing theories also consider automaticity, parallel distributed processing, and processing speed. The Stroop effect goes along with activities in the anterior cingulate cortex and the dorsolateral prefrontal cortex. Both areas are involved in the resolution of conflicting information in attentional processes and inhibition [19]. These brain regions will be covered by the applied EEG configuration.

The Stroop task relies on the differences in reaction times to congruent and incongruent stimuli [18]. In this experiment, the paradigm will be implemented along the standardized procedure. The name of a color will be presented (e.g., “red”) and the font color will be congruent (red) or incongruent (e.g., blue). The participant will have 2500 ms to respond. The feedback will be visual or auditory. The visual feedback will be given with a green (correct) or red (wrong response) dot that will be shown 500 ms after the response time. The feedback will be given in the visually or auditorily, depending on the the condition. With this manipulation at hand, the soundscape is either partially (auditory feedback) or fully (visually feedback) irrelevant. The listener can completely ignore the auditory modality in visual feedback condition but not in the visual feedback condition.

2.1.3 Noise Setting 1: Noise exposure

The noise in this experiment will be presented at a sound pressure level of 65 dB(A). The sound stimulus will contain a synthetically designed soundscape in a passenger high-speed train as it is found in mobile work. The auditory stimulus will be presented in all noise blocks equally and during the whole duration of the cognitive tasks. The noise exposure will be combined with and without task. In the task condition Stroop, the levels auditory and visual feedback are considered.

2.1.4 Noise Setting 2: Silence exposure

The silence exposure in this experiment will be presented at a sound pressure level of below 30 dB(A). No auditory stimulus will be presented. The silence exposure will be combined with and without task (Stroop, n-back).

2.1.5 Rest measurements

During the rest measurements at the start and end of the experiment, the EEG will be recorded in absence of a cognitive task twice: one time with and one time without an auditory stimulus. By comparing the data from noise/silence, auditory/visual feedback (auditory modality partially/completely irrelevant), task/no-task conditions, we will be able to make conclusive observations in the EEG correlates and control these neuronal dynamics with performance measures and subjective report (trait and state).

2.2 Disruptive soundscape

2.2.1 Mobile work: variability of sound sources

Mobile work becomes an option among employees in many professions [20]. The variety of noise during mobile work is infinite and detached from the work activities themselves. Remarkably, employees do not only choose quiet surroundings for their work tasks but sometimes also choose to work in surroundings with a moderate level of sound pressure [21]. Moderate levels can be judged sometimes more ergonomic as silent environments. The high-speed train and the table/desk combination in the train are representative of a new, flexible workstation [22-24].

The disruptive sound scenario that we investigate is mobile work – working on a train. Employees working in digital workflows often travel to business partners, customers, conferences, and commutes. During this time, it can be necessary to fulfill work tasks, like reading, writing, and answering phone calls. We test the needed executive functions for doing this with the cognitive tasks used [24].

2.2.2 Composition of synthetic soundscapes

For the digital composition of the soundscape, the Apple Logic Pro 10.7.5 software will be used. Based on the freesound (https://freesound.org) collaborative database (Creative Commons Licensed sounds) stand-alone sounds will be compiled into a coherent soundscape representing the train scenario [25]. The soundscape will be accessible together with the experimental data as supplement to the report on the experiment results. For the composition of the soundscape, different sound events are combined. The sound events include voices generated by the Google Speech Services (text-to-speech). Expert judgment from our institute will be involved in the design for composing a realistic representation of an actual situation in a moving train [24]. The involved expert is active in the research of mobile work and its effect on work performance, well-being, and stress [20, 23, 26].

The soundscape of the mobile work in a high-speed train is defined by machine sound, emitted by the train itself, and social noise from fellow passengers (conversations, phone calls, technical interactions), train conductor (giving information, checking tickets), security personnel (federal police officers), and service personal (selling goods) [27]. Beside these primary sounds, secondary social sounds relate to objects that are carried by passengers that produce sounds and signals (see Fig. 1).

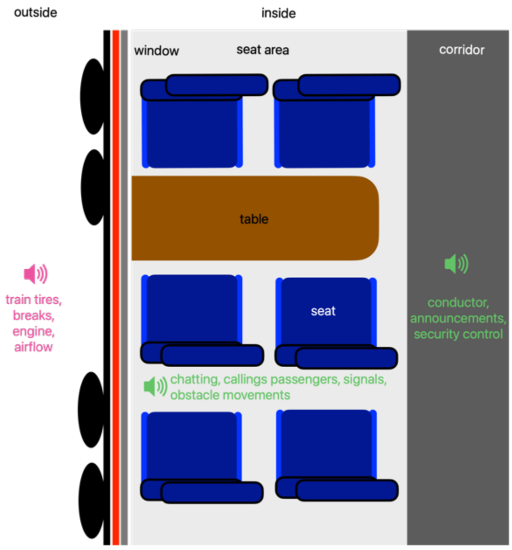

Figure 1. Soundscape design visualization (irrelevant sound sources) "mobile work, train scenario": primary and secondary social sounds (green), machine sounds (pink).

2.2.3 Noise filtering

The ignoring of potentially distracting soundscapes that contain irrelevant sound sources affects physiological (direct pathway) and psychological processes (indirect pathway) [28]. The auditory nerve activated by noise can directly influence other brain regions that are connected in a distributed manner. The filtration process can be also categorized as an indirect factor: the continuous decision-making process of what sound source is relevant, and which is irrelevant binds available cognitive resources that we study here. The soundscape contains different sound sources that emerge and eventually disappear again.

2.3 Measures, correlates, and scales

2.3.1 EEG

The EEG will be recorded by 25 electrodes (amplifier and recording software by BrainProducts GmbH) arranged according to the international 10-20 system with a sampling rate of 500 Hz. The Cz electrode will function as reference.

The experiment will be conducted in the shielded cabin of the EEG laboratory of our institute in Berlin. The participants will be monitored inside the cabin via video and instructed from a control room via an intercommunication system. The stimulus presentation will be controlled from outside the cabin.

2.3.2 NASA task load index

The NASA-TLX is a subjective assessment tool of the perceived workload that a participant experiences during processing tasks [29]. We will assess the NASA-TLX questionnaire after each task. The data will be used to control for the spectrum of perceived high and low workload blocks.

2.3.3 Weinstein's noise sensitivity scale

Noise sensitivity can be regarded as a personal trait and can be measured by self-report. The psychometric properties of Weinstein's noise sensitivity scale (WNS) have shown the appropriateness of the instrument to detect the general level of a person to be annoyed and dissatisfied by the noise that is below harmful sound pressure levels, so called auditory effects [30]. On this scale, the personal agreement with sound-related statements will be collected (e.g., "I find it hard to relax in a place that's noisy"). The data will be used to control for personality profile with high and low noise sensitivity.

2.3.4 Task performance

The task performance will be evaluated by consideration of speed (reaction time) and accuracy (correct/incorrect) in both the n-back (auditory feedback) and the Stroop tasks (visual/auditory feedback).

2.4 Experimental procedure

During the experiment, the participant will be sitting with EEG cap and headphones on a chair in front of a computer screen (50 – 60 cm). Motor responses will be collected with buttons on a mouse.

The study will take place on one day per subject and will consist of four parts: introduction and training, session 1, and session 2. Session 1 will include the n-back tasks and session 2 the Stroop tasks (auditory feedback). The order of the sessions will be counterbalanced over the participants.

The training period aims to make sure that the participant understands the respective task. All task tasks will be separated by a 2 min 30 sec break where the participants will answer the NASA-TLX questionnaire (see Fig. 2).

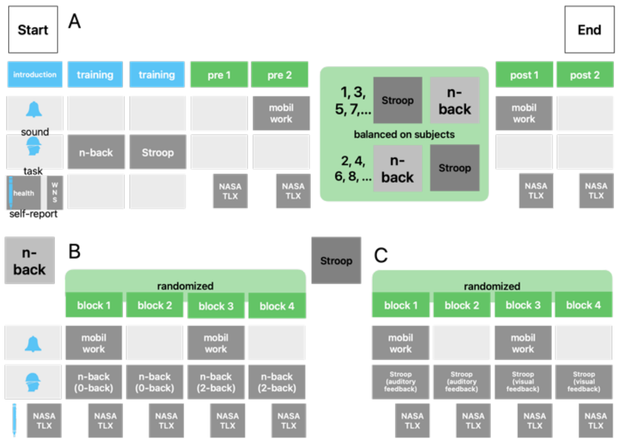

Figure 2. Experimental procedure and presented combinations. A: n-back, B: Stroop (A and B will ascribed to the recorded participants in alternating order).

2.4.1 n-back sessions

The 0-back and 2-back tasks will be presented with a duration of ca. 5 min each in four blocks. Both tasks (0-back and 2-back) will be presented in noise and silence in randomized order (see Fig. 2B).

2.4.2 Stroop sessions

The Stroop tasks will be presented in a session that consists of four blocks. The feedback of the Stroop task will be given in one block auditorily and in a second block visually. Both task versions will be presented in noise and silence. All tasks in the session will be presented in randomized order (see Fig. 2C).

2.4.3 General study information

The sample size aimed is a total of 16 participants for this feasibility study. The general health status regarding hearing and vision will be assessed by means of a questionnaire and a hearing test. The hearing test results will be used to select normal-hearing subjects und for the control of the experimental results statistically. The participants will give their written consent for participating voluntarily in the study, after being fully informed about the study aim, design, and recorded data. A financial compensation will be granted. The ethics committee of our institute will evaluate the study before the investigation can take place. The environmental parameters (temperature, humidity, airflow) will be controlled during the experiment on a constant level for all participants and recorded for report purposes.

3. PROPOSED ANALYSIS

3.1 Analysis of EEG data

The EEG will be analyzed primarily in the frequency domain [19]. Secondly, we will also consider analysis of event-related potentials in the time domain to evaluate and understand the human information processing. Artifacts will be removed from the EEG signal by means of independent component analysis [31, 32].

3.2 Analysis of behavioral and subjective data

The objective performance parameters (reaction time, accuracy) and the subjective self-reports will be analyzed in SPSS and R-Studio [33]. For the modelling of the data a generalized mixed model will be applied.

3.3 Multidimensional data extension

Furthermore, we aim to extend the number of registered bio signals during the experiment by simultaneous recording of skin conductance [34] and heart rate [35, 36]. We propose that cognitive shifts can be best observed in the EEG data while heart rate and skin conductance might add more insight regarding emotional reaction. The integration and interpretation of such multidimensional data can be reached by data mining and machine learning approaches.

4. OUTLOOK

In our study, we primarily address the question, of whether neuronal correlates are sensitive to fine-grained modulations of mental workload during audio-visual tasks. By this, we aim to determine whether it is possible to identify EEG parameters related to mental workload induced by visual-auditory cognitive tasks and the acoustic environment. Knowledge of biomarkers contributes to the ergonomic design of future workplaces. Nevertheless, our study is constructed as a pilot experiment with a limited number of tasks and participants. In case of promising results gained by the pilot experiment, future research will expand this preliminary research. Following studies, will address questions regarding intervention actions for understanding and mitigating potential risks by ergonomic design or organizational approaches.

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