Bachelor Thesis Research Proposal: Effect of stimulus duration on Event-related potentials during a rapid serial presentation task

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***Abstract*—This research proposal is for the Bachelor thesis of Jan Sauter on the effect of stimulus duration on event-related potentials (ERP) during a rapid serial presentation task. This effect will be evaluated by analyzing electroencephalography (EEG) data collected during a study in which participants were presented images of human faces as visual stimuli in a rapid serial presentation scenario. For the analysis regression-based models will be used in order to model varying stimulus duration as a marginal effect on in order to assess the effect of stimulus duration on the ERP. Additionally the application of deconvolution-based overlap correction in rapid serial presentation scenarios will be assessed.**

I. Introduction

Brain activity can be measured using µ-volt measurements via electrodes placed on the human scalp. This process is called electroencephalography (EEG). This activity is often measured over multiple trials in relation to an event and then averaged over these events to obtain the event-related potential (ERP). However, calculating ERPs in this way is 'flawed' in a sense, since they cannot account for trial-wise influences on the brains response. One of these trial-wise influences can be the duration of a stimulus. Therefore, the question of how the duration of a certain stimulus affects the brains response to that stimulus arises. In order to examine this relation, I will analyze data previously collected during a study by Geiger. During the study 38 participants were presented images of human faces at a rate of multiple faces per second. The experiment consisted of 10 blocks, consisting of 20 images each, per participant. Half the blocks contained blanks (black screen with a fixation cross) between images, while the others did not (i.e. images were in direct succession without blocks). The duration of how long an image was shown was hereby randomly selected from a loguniform distribution with durations from 100-1500 ms. One task of this Bachelor thesis will be to analyze the data collected during this study in order to assess the influence of stimulus duration (here image of human face as stimulus) on the ERP of the participants.

A. Stimulus Duration

Stimulus duration is a critical parameter in the design of ERP experiments, as it can influence both the magnitude and timing of neural responses. Early ERP components such as the P1 and N170 are primarily time-locked to stimulus onset and reflect early perceptual and category-specific visual processing. These components tend to be relatively insensitive to stimulus duration beyond a minimal visibility threshold [1]. Therefore, brief stimulus presentations (e.g., 100–200 ms) are typically sufficient to elicit robust early ERP responses, particularly for well-defined stimuli such as faces or objects.

In contrast, later ERP components, including the P3, late positive potential (LPP) and N400, are more sensitive to the amount of time available for cognitive processing. Longer stimulus durations can enhance these components by allowing greater engagement of attentional, memory-related, or semantic processes [2]. This is particularly relevant in tasks that require stimulus evaluation, decision-making, or emotional appraisal. Moreover, very short or masked stimulus presentations may limit the emergence of late components, thereby constraining the interpretability of higher-order cognitive responses.

B. Overlap and Deconvolution

A key issue when analyzing the ERPs of a rapid serial presentation task, like the blocks in the aforementioned study, is the overlap between ERP responses of subsequent stimuli. The usual ERP response to a human face is characterized by a strong pronunciation of the N170 component [3], but studies also found relations to components that occur later like the LPP [4], which means that the typical ERP belonging to a human face as a stimulus can last for at least 600 ms. This duration causes ERPs belonging to subsequent stimuli to overlap in a rapid serial presentation paradigm. That overlap between ERP responses can cause problems when analyzing the data, which is why it is necessary to disentangle the potentials in order to interpret them correctly. One technique used in these scenarios is deconvolution, which can be applied inside the mass-univariate regression framework *rERP* introduced by Smith and Kutas [5], in order to transform the preprocessed EEG data to ERPs and additionally correcting the overlap between ERP responses of subsequent stimuli. This deconvolution technique is available in the toolbox *Unfold.jl*

[6], implemented in the programming language Julia [7]. The application of this toolbox specifically regarding deconvolution as well as by modeling duration effects linearly and non-linearly, will be a significant part of the thesis.

II. Related Work

A work closely related to the topic of this Bachelor thesis is a paper by Skukies et al. [8], which addresses the issue that brain responses (i.e. ERPs) vary in duration due to factors like reaction time and stimulus duration. Because of that, standard ERP averaging, without taking into account the varying response duration, can distort ERP shapes and lead to faulty results. Therefore they suggest combining linear deconvolution (to account for overlapping events) with non-linear modeling of event durations to avoid biased ERP interpretations. Regarding the modeling of event durations spline based regression seemed to be the best-performing technique for modeling these effects.

A second closely related work that discusses the effect stimulus duration during face recognition tasks (i.e. also human faces as visual stimuli) is by Tanskanen et al. [9]. The objective of the study was to investigate the effect of stimulus duration on the face recognition performance and the cortical response, particularly the M170 and M300 responses. The study was conducted with 9 participants and they were given the task to identify images of human faces, presented for a duration of 17-200 ms, as one of 6 pre-learned faces. The neural response was meanwhile recorded by Magnetoencephalograph (MEG). Results showed that for a stimulus duration of 17–33 ms recognition performance was at chance level, but improved steeply 50–83 ms before plateauing at around 100 ms. Regarding the M170 and M300 components of the cortical responses they discovered that the amplitudes of both increased with stimulus duration, even after behavioral recognition plateaued. However,y identified a strong correlation between the recognition performance and the amplitudes of the M170 and M300 components. With that said, the study provides strong empirical evidence that ERP components are sensitive to stimulus duration, regarding faces as a visual stimulus.

A third work broadly related to the topic of this thesis is a paper by Capilla et al. [10]. They argue that Steady-State Visual Evoked Potentials (SSVEP) can be fully explained by summation of transient ERPs which are caused by individual stimuli. This is also called the Superposition hypothesis. Contrary to that, another hypothesis, which could not be verified by Capilla et al., is that SSVEPs result from so-called neural entrainment, which means that the brains internal rythm, captured by EEG, synchronizes with the frequency of the visual stimulus. This paper is insofar relevant to this thesis since it also looked at the meaning of overlap between ERPs and tied it to the topic of SSVEPs, even arguing that SSVEPs are simply a summation of overlapping ERPs and therefore unifying the view on transient and steady-state responses.

Another work which is essential for this Bachelor thesis, is a paper by Benedikt Ehinger and Olaf Dimigen [11], which introduces the previously mentioned toolbox *Unfold*. However, the in the paper introduced version is the initial MATLAB implementation of the toolbox and not the Julia implementation used for this Thesis. The open-source toolbox is designed for advanced EEG analysis, based on the regression-based rERP framework. The two main features relevant for this thesis are once the linear deconvolution in order to carry out overlap correction between ERPs regarding consecutive stimuli and secondly regression based modeling in order to model both linear and non-linear covariate effects, which is especially important when investigating the effect of stimulus duration on the brain responses. Therefore the usage of this toolbox will be essential during this thesis.

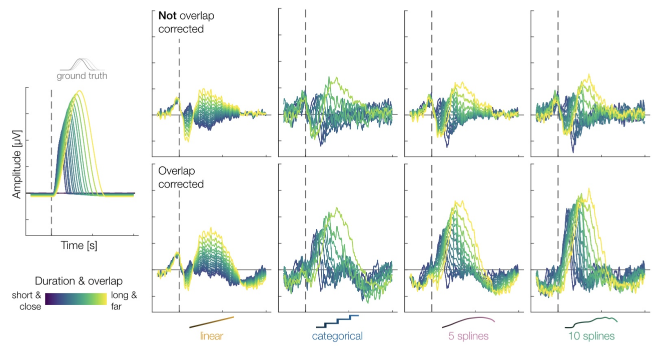

Fig. 1. Comparison of duration models with and without overlap correction from the paper *'Brain responses vary in duration - modeling strategies and challenges'* by Skukies et al. [8]. CC BY 4.0

III. Mandatory and Optional Goals

The primary scientific goal of the thesis will be the assessment of how a stimulus duration - which is in the case of the underlying study the presentation time of a face image - affects the brain response (here ERP) on a sub-second scale. This assessment will be conducted by analyzing the EEG data collected in the study by Martin Geiger. On a methodological level this means applying mass-univariate modeling including deconvolution on the EEG data in order to carry out overlap correction between ERP responses. This will be done in order to reach the scientific goal, but also assess the general applicability of deconvolution in order to analyze ERPs in rapid serial presentation paradigms. The application of deconvolution will hereby be applied using the Julia toolbox *Unfold.jl* [6], where the influence of stimulus duration in a non-linear manner will be assessed in the univariate regression of the deconvolution process.

As a further stretch goals firstly a comparison between different relations (linear, non-linear) of stimulus durations and brain responses (ERPs) will be made. Secondly the effect of using blanks in a rapid serial presentation scenario will be assessed in order to investigate wether their application is viable in these scenarios or if jitter is too high.

IV. Approach

The beginning of the thesis will mainly consist out of conducting further literature review and broaden my understanding of the field of EEG analysis. A resource that I imagine to be very insightful is a book on the ERP technique by Steven J. Luck [1]. The literature review will mostly focus on the topics of the effect of stimulus duration on ERPs and the overlap correction techniques such as deconvolution, but also beyond that.

Since I will be using the toolbox *Unfold.jl* for the data analysis I will also familiarize myself further with the programming language *Julia*, by continuing to implement exercises from the EEG lecture by Bendikt Ehinger in it, as well as familiarize myself further with the regression-based rERP framework that's underlying the toolbox.

As soon as the dataset is available, I will also start with the data exploration, before going over to the data analysis section, where I will apply different modeling strategies in order to model the effect of stimulus duration as a marginal effect in the rERP framework. Figure 1 shows a comparison of different modeling techniques similar to what I want to create.

Depending on the quality of results the data analysis part will mostly likely be conducted in multiple iterations trying out different data preprocessing techniques as well.

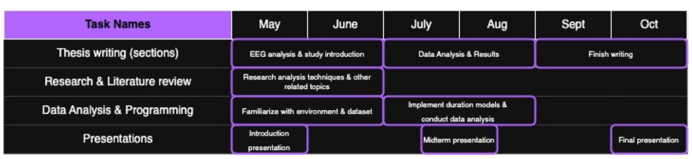

Fig. 2. Schedule for thesis starting in May 2025

V. Schedule

Regarding the timeline of the thesis, Figure 2 gives a rough outline. The first two months will hereby mainly consist of further research into the EEG analysis techniques deconvolution and regression based modeling of stimulus duration on a more technical level, as well as broaden my general understanding of the matter. At the same time I'll also write the first sections of the thesis regarding the general topic of EEG anlysis - ERPs in particular - and the section regarding the study, from which the dataset originates. I'll also familiarize myself with the programming language *Julia* and the toolbox *Unfold.jl*, which I intend to use manly for the data analysis. Additionally I'll explore the data, before starting in the third month with the actual analysis and comparison of the different duration models. At the end of the third month I will then hold my midterm talk, which should ideally be at the end or at least close to the end of my data analysis, so that I can present my findings there already. After that I'll incorporate the feedback from the midterm talk into my current data analysis and possibly even add some new parts to it, depending on the feedback. Then the last two months will be used to finish the writing of the thesis and prepare for the final presentation of the results.

References

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