Identifying the State of Cognitive Flow Using EEG and Other Physiological Signals

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***Abstract*— This research project aims to discover identifiers for the cognitive flow state within EEG signals and / or EEG behaviour over time patterns. This would lead to better games in the future, giving developers more knowledge into what makes games immersive, as well as giving them a tool to measure that effect. The plan for the project involves gathering data from a number of participants of different levels in terms of games experience, playing different types of games based on the stage of the study, in a carefully designed experiment that reduces data corruption as much as possible, and analyzing the data in an exploratory process of pattern matching and artifact discovery.**

I. INTRODUCTION

The brain is a highly complex part of the human body, responsible mainly for coordinating quite literally everything that happens, from basic tasks such as breathing and moving to responses to external stimuli, emotions, learning etc. Anatomically speaking, it can be seen as an overly complex net- work of neurons, constantly traversed by electrical impulses of different intensities, generating signals that travel from one part of the other, triggering the appropriate reactions. These signals are the subject of this project. More specifically, trying to understand what these signals look like during different mental tasks or states, and how they propagate within the brain.

A rather intense mental state has been chosen for the purpose of this project: the state of cognitive flow (flow theory (Csikszentmihalyi and Csikszentmihalyi 1992)). Understanding this state by means of brain signals (EEG) and other measurements will not only benefit computer games, as developers and designers would have a tool to tell them which part of their game is good and which is not, but may also reveal important knowledge regarding the way the brain functions, leading to advances in a number of disciplines (neuroscience, psychology, etc.).

Brain-computer interfaces are devices that use electrodes to record EEG signals at the surface of the scalp. These are non-invasive devices (although potentially uncomfortable at times), which allow for safe recordings of these signals, sacrificing signal clarity (measurement precision) compared to implanted electrode systems. There are differences between the different types of BCI devices, thus, trade-offs to be taken into consideration regarding hardware choice. For ex- ample, a device with a higher signal resolution and more electrodes will more than likely be difficult to set up, uncomfortable to wear for a long time and a pain to remove. However, an easier to use headset with only few electrodes, eventually dry (what we would call a consumer grade BCI today) would yield very poor quality signals.

In short, this project attempts to identify immersion and the state of cognitive flow using BCIs and EEG signals, and validating the results using different body measurements and self-reporting methods.

II. PLAN

The plan for the project is as follows:

- implement data recording
- design initial experiment
- record data with a small number of participants
- analyse data and identify initial results and areas of potential interest
- redesign experiment around the initial discoveries
- record data with a large number of participants
- analyse all data and ensure statistical significance of findings
- report the findings.

A rather typical plan for this type of task, which still holds a number of pit falls (the more obvious would be related to the possibility of results contradicting the initial hypothesis, as well as issues regarding data validation).

In case of contradiction of the original hypothesis, I will attempt to use the data or collect more data to ensure that no markers can be found, and report that instead. It is an exploratory process for a reason, and if the exploration shows that the suggested methods do not work, then that is valuable information as well, as at the very least it can spare another researchers time should they get the same research idea at a later date. This would also benefit the games industry, as it would save companies time and expenses on trying the same approach.

III. METHODS

This study has a predominantly exploratory nature (the research question is of the form: are there any identifiers?). Thus attempting to extract as much information as possible from the data available is paramount. Diversity of techniques attempted at the very least in the initial stages of the analysis process must be very high, in order to maximise the chances of finding useful patterns or features should there be any, or

to confirm that there is nothing to be found in that case.
The approaches I consider taking in order to answer the research question fall into different categories: connectomics analysis, classical EEG signal processing techniques (feature analysis and classification), signal behaviour over time analysis and perhaps statistical analysis of signals (averages over periods of time).
Connectomics are a very new paradigm for interpreting eeg signals. This makes this study potentially valuable in terms of research into brain area interconnectivity as well, which is one aspect I am certainly planning to explore once the data is available. The techniques in this paradigm involve treating the signals as a network, each electrode being a node in that network (functional connectivity graphs (Iakovidou et al. 2013)).

IV. Features

Feature extraction and analysis, the usual approach to eeg signal processing, is a must try form of analysis. A balance must be struck, however, between exploring as many features as possible, and using features previous literature found to be good ((Liu, Chiang, and Chu 2013), (Plotnikov et al. 2012) and many others). Once a set of features has been decided, an appropriate classification algorithm must be chosen and trained, as previously described. This choice will be based on the number of features, the type of data as well as the computational demands of the final system and practical performance of the algorithm. The most important factor in deciding the final algorithm(s) will be empiric results.
Some people have already made early attempts at using EEG for measuring focus and the flow state. Their attempts seem to have concluded that low beta band signals may hold significant information (Berta et al. 2013). This study will analyse that possibility further, but will also explore many more options as there is a high chance to find correlations by attempting as many different techniques as possible.
As a special mention, Plotnikovs study sets out as a proof of concept study, demonstrating that potential exists for the identification of the flow state in EEG signals. However, the study is a small one, with a number of issues, such as the choice of game, the BCI system used (not research grade equipment), very brief information regarding the experiment design etc. It is a small study meant to prove that potential exists in the area. The aim of this study is to perform a rigorous experiment in multiple steps in order to identify markers for the flow state or at the very least an immersion state with confidence.

A. *Over time analysis and statistics*

Signal behaviour over time analysis is, in my opinion, essential for this task. In order to see exactly what happens with the signals as the participants switch from a baseline state towards a flow state and what a flow state looks and evolves like is of very high interest. Synchronicity is one of the features that are directed at this type of analysis. Joint time frequency analysis and wavelet transforms are also very useful. Statistical analysis of signals based on averages over time can be a good indicative for the presence of potential markers. Mainly, if the averages vary significantly from one period of time to the other, there is a high chance of being able to identify exactly what changed as well.

V. Conclusions

The ideal outcome of this research project would be identifying markers for the cognitive flow state in EEG signals, thus being able to classify a given trial into flow state vs other states, as well as identifying what leads to the flow state in a computer game and how it occurs. Other potential results could lead to further advances in the area of connectomics and brain behaviour analysis, as well as discovering whether the EEG signals follow certain patterns when performing certain tasks. This would be a good confirmation of the hypothesis that the brain has neural patterns that the signals follow when given known mental tasks.
Future work will involve attempting to discover identifiers and behaviour pattern changes related to emotional states, as well as further research into brain area interconnectivity and communication. Furthermore, finding new ways of integrating emotional awareness into computer games is another step to be taken, as it would give designers more knowledge about what makes their games fun and also help developers make more engaging and fun games.

VI. References

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