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# A Proposed Method of Matching ACT-R and EEG-Data

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## Introduction

Most model-based research in neuroscience is limited to fine grained analysis of single cognitive process. The question how different brain regions interact with each other is a matter of ongoing research and far from being answered. Methods, which unite findings and methods of cognitive modeling and neuroscience are required, in order to obtain greater understanding of cognitive processes of the human brain. The objective of this paper is to propose a matching method that links Independent Components (ICs) derived from EEG-data (Electroencephalography) and ACT-R buffer activation, using dipole fitting and cross-correlation analysis.

## Theory

### ACT-R

ACT-R is a cognitive architecture, which consists of different modules (visual, goal, declarative, imaginal, motor, procedural and others). Buffers are the interfaces of the modules and interact via a (rule-based) production system. ACT-R has the advantage that human cognition, as a whole, in contrast to other approaches that only focus on single cognitive processing steps, is modeled. Nevertheless, predictions of perception, action and cognition steps are provided by ACT-R models, in the range of milliseconds.

### FMRI & ACT-R

There is growing research that combines ACT-R theory with findings from neuroimaging techniques. In recent years many studies have emerged that compare ACT-R module activity with brain activity as measured in fMRI (functional magnetic resonance imaging) studies. The combination of ACT-R and fMRI provides information about a) the localization of specific modules (e.g. procedural components in basal ganglia) and b) the plausibility of the architecture (e.g. reasonability to assume a specific module) (Anderson, 2008). But, information concerning the exact timing of cognitive processes cannot be obtained with fMRI.

### EEG and ACT-R

EEG (electroencephalography) measures voltage fluctuations of neurons. Thus, it reflects a large amount of ongoing brain processes. Different components of EEG activity are linked to different information processing stages and different parts of the brain. EEG has a very high temporal (milliseconds) resolution. The low spatial resolution of EEG data is a disadvantage compared to FMRI data. But methods like Independent Component Analysis (ICA) possibly hold the potential to overcome this limitation (Delorme, Palmer, Onton, Oostenveld & Makeig, 2012). ICA separates a set of mixed signals into their respective source. ICA determines which temporally independent and spatially fixed activations make up a time-varying response. By using ICA, it is possible to approximate where signal components originate and separate the mixed signals on into different components Thus, theoretically the source of activation can be found.

Only few studies attempted to combine ACT-R models with EEG data; even though EEG and ACT-R allow milliseconds precise information about the timing of processes, whereas fMRI does not.

Two EEG-ACT-R studies have merely dealt with timing issues of certain request (Cassenti, Kerick & McDowell, 2011; Cassenti, 2007). Two different studies have applied ICs in order to gain information about module activation, but both had severe methodological limitations since they measured EEG with only five channels (Griffiths & West, D'Angiulli, A., 2011) or only one subject (Prins, 2010). In a more promising study, Van Vugt investigated coherences between EEG- frequency bands and buffer activity (Van Vugt, 2014). She found a link between theta frequency bands and working memory modules of ACT-R. Recently, semi-hidden Markov-models were used on EEG data to indentify the number and duration of cognitive processing stages (Borst & Anderson, 2015; Anderson, Zhang, Borst, & Walsh, 2016). These processing stages were then qualitative compared to the predictions of different theoretical models, including an ACT-R model.

### Objective

Our goal is to develop a method, which directly combines ACT-R activation and ICs of EEG-activation. The main advantage is using the potential of EEG-data for qualitative and quantitative model validation. In order to assess whether the ACT-R formalized theory represents real human behavior, experimental data is collected. Therefore, participants perform the same task as the model. To validate the modeled data, the matching of modeled data and participant data is assessed via Goodness of Fit Indices. In general, behavioral data (reaction time, mistakes) is consulted for this assessment. If the overall fit of a model reproduces the data well, this is seen as an indication that human information processing, as formalized in the model, could well proceed in this way. However, it is possible, that models postulating different processing steps, achieve a similar match to behavioral data. Using EEG-data could allow process validation of models. If the ICs were to match to specific model components then the timing of peaks of buffer activity should match IC-peaks. In order to discover which aspects of human information processing are linked to which EEG components is another important advantage of the proposed method.

## Matching Method

The following section outlines the main steps:

The *first step* is to find an experimental paradigm, meeting the following demands: Ideally, it is a well studied paradigm, for which high-quality EEG-data, with a decent spatial resolution and ACT-R models exist. A further requirement for the paradigm is that, it produces activity over the neocortex, preferably in well separated areas and that the ACT-R model utilizes different ACT-R modules.

The *second step* is then to fit the model-data to the behavioral-data of the EEG-study. The duration for the task for the model should match the average duration of the participants (e.g. $r^2$ should be above 0.800 and RSME should be small). Parameters of the model could be adjusted in order to achieve a fit satisfying these constraints.

The *third* step is then to use a linear transformation to scale the model activity on a trial-by-trial so that the behavioral data and the model data achieve a perfect fit. Such a procedure was introduced by Borst, Taatgen and Van Rijin, 2011 in order to match fMRI to ACT-R data.

The *forth step* requires displaying ACT-R buffer activity in milliseconds. This can be achieved by averaging data from multiple model runs for each buffer, as done by Van Vugt (2013). In summary, data from multiple model runs is averaged, using as many model runs as trials in the EEG data. In order for the modeled and the EEG data to have the same amount of data points, the average module activation of each buffer needs to be sampled to the EEG sampling rate. The *fifth step* concerns the EEG-data. The EEG-data needs to be transformed into Independent Components (ICs). This will result in as many components as there are EEG channels and thus more ICs then modules. For a cross-validation (see step sixth) dipole fitting (see Griffiths and West, 2011 for an example of how this method works in combination of ACT-R) should be deployed. With dipole fitting the sources of the ICs in the neocortex can be found.

The *sixth step* involves the actual matching of EEG and ACT-R data. A correlation method should be applied. Cross-correlation analysis is a promising approach, as it can be used to find correlations between matrices.

After ICs that match buffer activation are found, *the seventh step* proceeds to cross-validate the components using dipole fitting; the sources of the selected ICs should be located in brain regions that have been identified to locate the ACT-R modules (Anderson, 2008).

The *eigth step* analyses and describes ICs that are associated with different buffers.

Finally, as a *ninth step*, these previously identified characteristics will be used on different data.

## Discussion & Outlook

Taken together, research in the field of linking ACT-R and EEG-data is so far limited. But, important findings, concerning cognitive theory and its neural correlates, could derive from combining data of ACT-R models and EEG-activation.

To implement the proposed matching method, we are searching for a suitable paradigm. The main requirement is that an ACT-R model for this paradigm uses numerous ACT-R modules, with uncorrelated activation and that EEG data exist.

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