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Improved estimates of BCI accuracy with hierarchical Bayesian models

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Introduction: Recent replication failures in psychology [1] and the prevalence of low-powered studies in neuroscience [2] have prompted calls for reform of statistical practices, with the current situation even being characterized as a "statistical crisis" [3]. One commonly identified problem is the over-reliance on null hypothesis significance testing (i.e. *p*-values), and a commonly proposed solution is to move towards parameter estimation and towards Bayesian methods [4]. Although hierarchical Bayesian models of accuracy have already been proposed for brain decoding studies [5], they have not been directly compared to their non-hierarchical Bayesian versions. In this abstract we present a simulation study of Bayesian models of accuracy, and show that hierarchical models improve subject-wise estimates of accuracy, compared to non-hierarchical models.

Material, Methods and Results: The hierarchical model of accuracy is shown in Fig. 1.A. In the non-hierarchical model subject-wise accuracies ψ_i are considered as directly observed, without sampling error, and their values are set at y_i / T_i; the non-hierarchical model is otherwise identical to the hierarchical model. The simulated accuracies were obtained using the hierarchical model as a generative model. We simulated 2500 experiments, with the number of subjects per experiment uniformly sampled between 5 and 20, and the number of trials per subject uniformly sampled between 20 and 200. The group-wise accuracy μ_α for each experiment was uniformly sampled between 0.55 and 0.95 on the probability scale, and std. dev. σ_α was uniformly sampled between 0.2 and 0.8 on the log-odds scale. The Bayesian inference was performed using Markov chain Monte Carlo simulation. The errors in subject-wise accuracy estimates for the two models are shown in Fig. 1.B.

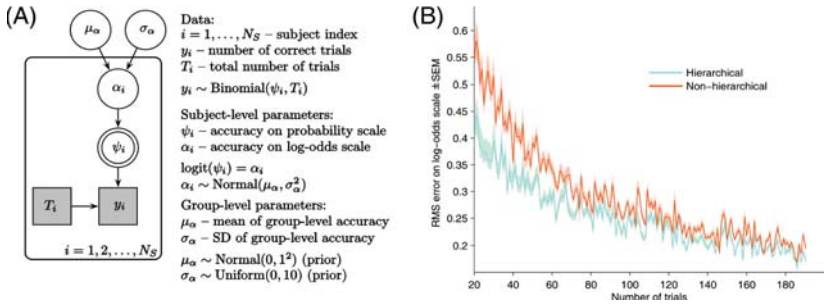

Figure 1. *(A) The hierarchical model of BCI accuracy in a group of users. (B) Root-mean-square (RMS) error in the subject-wise accuracy estimates on the log-odds scale, depending on the type of the model and the number of trials for the subject.*

Discussion: The subject-wise estimates of accuracy are improved using the hierarchical model, especially for subjects with low number of trials, without the loss of accuracy at the group-level estimates (group-level results omitted here for space). The reason for the improvement is the pooling of information across subjects. Moreover, using the Bayesian hierarchical model, a full posterior distribution for subject-wise accuracies is available, rather than just a point estimate such as sample accuracy used in the non-hierarchical model.

Significance: We demonstrate the effectiveness of the hierarchical Bayesian model of BCI accuracy, and show it to be superior to the non-hierarchical model in estimating subject-wise accuracy. The improvement is particularly evident when a low number of trials is available for a subject, which is a common situation in BCI research.

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