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Cerebral Cortex, 2025, **35**, bhaf239
https://doi.org/10.1093/cercor/bhaf239
Advance access publication date 10 September 2025
Commentary

Statistical parametric mapping: a catalyst for cognitive neuroscience

Klaas Enno Stephan [1,2,*]

[1]Translational Neuromodeling Unit (TNU), Institute for Biomedical Engineering, University of Zurich & ETH Zurich, Zurich, Switzerland
[2]Max Planck Institute for Metabolism Research, Cologne, Germany
*Corresponding author: Translational Neuromodeling Unit (TNU), Institute for Biomedical Engineering, University of Zurich & ETH Zurich, Zurich, Switzerland. Email: stephan@biomed.ee.ethz.ch

Statistical Parametric Mapping (SPM) is a statistical framework and open source software package for neuroimaging data analysis. Originally created by Karl Friston in the early 1990s, it has been used by a vast number of scientific studies over the last three decades. SPM has not only revolutionized the analysis of neuroimaging data but also catalyzed the development of cognitive neuroscience. This short commentary reflects on key principles that have made SPM so enormously influential and successful: (i) the introduction of a principled general framework for statistical inference that applied to all neuroimaging modalities, (ii) the emphasis on open source code, transparency, and collaboration, and (iii) constant evolution over three decades, from a frequentist mass-univariate framework to generative models of neuroimaging, electrophysiological, magnetoencephalographic, and behavioral data.

Keywords: SPM; functional magnetic resonance imaging; electroencephalography; optically pumped magnetometry; magnetoencephalography; positron emission tomography.

Klaas Enno Stephan is a computational neuroscientist and medical doctor. He is Full Professor of Translational Neuromodeling & Computational Psychiatry at the University of Zurich & ETH Zurich and founding director of the Translational Neuromodeling Unit (TNU). His research focuses on translating advances in computational neuroscience into clinical applications – from the development of disease theories via the creation of computational methods to clinical studies.

Cognitive neuroscience only came into existence as a scientific discipline a few decades ago but was quickly recognized as essential to the scientific enquiry into the function(s) of the human brain. Resulting from a merger of approaches from neuroscience and cognitive science in the late 1970s (Cognitive Neuroscience Society 2025), the development of cognitive neuroscience accelerated in the 1990s due to the advent of non-invasive neuroimaging techniques, including positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). The impact of neuroimaging on cognitive neuroscience is difficult to overstate but did not simply result from the availability of new measurement techniques. Instead, this impact would hardly have materialized without a novel analysis framework that spanned all neuroimaging modalities and standardized data analyses while integrating the experimental designs of cognitive neuroscience into the toolkit of neuroimaging. This framework was provided by Statistical Parametric Mapping, widely known as SPM.

After the first version of SPM had been developed and released by Karl Friston in 1991 followed by a major revision in 1994 (Functional Imaging Laboratory 2025), it saw continued development by Karl, his team, and an international community of collaborators, as described in the article by Zeidman et al. in this issue. Since its inception, SPM has kept evolving and continues to shape neuroimaging and cognitive neuroscience until today. Three decades is an unusually long period for a purely academic software to exist, enjoy enormous popularity, and stay at the top of the game. This short commentary reflects on the principles that have made SPM so enormously influential and successful.

First, SPM introduced a principled and general framework for statistical inference that applied to all neuroimaging modalities alike and even extends to electroencephalography (EEG) or magnetoencephalography (MEG). One key conceptual decision was to treat all neuroimaging data as spatially smooth images which allowed for exploiting random field theory as a modality-independent approach to deal with the challenge of multiple testing. Furthermore, SPM emphasized that all commonly used null hypothesis tests could be understood as special use cases of

Received: August 5, 2025. **Accepted:** August 5, 2025

the general linear model (GLM; Friston et al. 1994). The choice of the GLM as a flexible "mother model" was essential for connecting neuroimaging to cognitive neuroscience since this allowed neuroimaging researchers to exploit the same experimental designs as in cognitive neuroscience, eg categorical, factorial, and parametric designs. Last but not least, SPM introduced the notion of mass-univariate modeling, ie the approach of creating a statistical model (ie a GLM) that explained data in a voxel-wise fashion as resulting from a mixture of intended (experimentally controlled) and unintended (nuisance) effects. Combined with RFT, mass-univariate models provided a statistically solid fundament for discovery imaging science—ie whole-brain frequentist inference about spatially extended neuronal processes—that has been used by the vast majority of task-based neuroimaging studies to date.

Second, SPM prioritized openness and transparency. Its code was open from the very beginning, a long time before 'open source' became a widely valued principle in science. This not only allowed users to understand its operations in mathematical detail, but also enabled them to contribute improvements and extensions. However, SPM was always more than just code: It provided a novel paradigm for testing scientific questions of functional localization and functional integration—and it offered in-depth teaching courses to international participants. Overall, this led to the growth of a large global community of neuroscientists with a shared perspective on how brain functions were to be investigated and inspired numerous other neuroimaging software packages that have inherited and built on many of the concepts that SPM had introduced and popularized.

Third, SPM has constantly been evolving and blazing new trails for neuroimaging—and beyond. Originally designed for the mass-univariate analysis of PET and fMRI data, SPM has grown to encompass an impressively broad set of functions. Voxel-based morphometry was introduced in the late 1990s (Ashburner and Friston 2000), as were methods for context-dependent functional connectivity (psycho-physiological interactions; Friston et al. 1997). In the 2000s, SPM increasingly begun to embrace a Bayesian perspective on data analysis, leading to fully generative models of neuroimaging data that characterized the joint probability of data and parameters (Friston et al. 2002). This switch to a Bayesian perspective proved enormously fruitful, culminating in the development of dynamic causal modeling (DCM; Friston et al. 2003). DCM represents a generative modeling framework that explains how measurements can be understood as the noisy observation of the dynamics of latent (hidden) processes, including—but not limited to—neuronal populations that interact via synaptic connections. In neuroimaging, DCMs have not only proven useful for analyses of effective connectivity and mechanistic (biophysical) insights into neural circuits, but represent a promising basis for computational assays of clinically relevant pathophysiological processes (eg Symmonds et al. 2018)—a key theme in computational psychiatry (Stephan and Mathys 2014). The most recent evolutionary step of SPM concerns the integration of a generative modeling framework for behavioral data, called active inference. Based on the free energy principle (Friston 2010), active inference proposes that, like perception, actions serve to minimize (a free energy bound to) information theoretic surprise (Parr and Friston 2019). Its implementation in SPM allows for analyzing a wide range of behavioral and physiological data and for integrating inferred computational quantities directly into neuroimaging data analyses.

Over the last three decades, SPM has been facilitating and enabling the work of tens of thousands of neuroscientists. It is tempting to speculate what the future may bring. As already mentioned by Zeidman et al (Zeidman et al. 2025), one obvious path of development concerns the coverage of data from optically pumped magnetometry (Tierney et al. 2019)—a novel technology that promises great advances for MEG but is also associated with interesting challenges. A further aspect is the possibility of SPM evolving into a multi-language model. Here, exciting opportunities exist for exploiting modern programming languages specifically designed for high-performance scientific computing, such as Julia (Bezanson et al. 2017). Finally, might the recent integration of generative models of behavioral data mark the beginning of a process by which non-neuroimaging data could eventually become equally important for SPM, perhaps leading to generative models that fuse multiple data types, eg from multimodal measurements in naturalistic contexts?

Whatever the future may bring, for today, all that remains to say is: Happy birthday, SPM!

Acknowledgments

The author is grateful for generous support by the René and Susanne Braginsky Foundation, the ETH Foundation, and the University of Zurich. This is a human written manuscript without the use of artificial intelligence.

Author contributions

Klaas E Stephan (Conceptualization, Writing—original draft).

Funding

None declared.

Conflict of interest statement: The author has contributed code to the SPM software and both participated in and organized SPM teaching courses in the past.

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