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statConfR: An R Package for Static Models of Decision Confidence and Metacognition

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Summary

We present the `statConfR` package for R, which allows researchers to model binary discrimination responses and confidence ratings. For this purpose, the package provides functions to conveniently fit nine different static models of decision confidence:

- the signal detection rating model (Green & Swets, 1966),
- the Gaussian noise model (Maniscalco & Lau, 2016),
- the independent Gaussian model (Rausch & Zehetleitner, 2017),
- the weighted evidence and visibility model (Rausch et al., 2018),
- the lognormal noise model (Shekhar & Rahnev, 2021),
- the lognormal weighted evidence and visibility model (Shekhar & Rahnev, 2024),
- the independent truncated Gaussian model (Rausch et al., 2023) based on the model specification used for the original meta-d′/d′ method (Maniscalco & Lau, 2012; Maniscalco & Lau, 2014), and
- the independent truncated Gaussian model based on the model specification of Hmetad (Fleming, 2017).

In addition, the `statConfR` package provides functions for estimating different measures of metacognitive sensitivity (i.e., the degree to which humans are able to differentiate between correct and incorrect trials) and metacognitive efficiency (i.e., metacognitive sensitivity in relation to the ability to perform the task):

- meta-d′/d′, the most widely-used measure of metacognitive efficiency, allowing both Maniscalco & Lau (2012)'s and Fleming (2017)'s model specification,
- Information-theoretic measures (Dayan, 2023), including
  - meta-I, an information-theoretic measures of metacognitive sensitivity,
  - $meta - I_1^r$ and $meta - I_2^r$, two measures of metacognitive efficiency proposed by Dayan (2023),
  - RMI, a novel measure of metacognitive accuracy, also derived from information theory.

Finally, the `statConfR` package includes an example data set previously published in Hellmann et al. (2023), with which the functions can be tested.

Statement of need

Cognitive models of confidence are currently used implicitly and explicitly in a wide range of research areas in the cognitive sciences: In perception research, confidence judgments can be used to quantify perceptual sensitivity based on receiver operating characteristics (Egan et al., 1959), a method based on the signal detection rating model (Green & Swets, 1966; Hautus et al., 2021). In metacognition research, the most popular measure of metacognitive performance, the meta-d′/d′ method (Maniscalco & Lau, 2012; Maniscalco & Lau, 2014), implicitly relies on the independent truncated Gaussian model (Rausch et al., 2023). Finally, confidence models have become a flourishing research topic in their own right (Boundy-Singer et al., 2022; Desender et al., 2021; Guggenmos, 2022; Hellmann et al., 2023, 2024; Pereira et al., 2021; Rausch et al., 2018, 2020; Shekhar & Rahnev, 2021, 2024). However, too few studies have empirically compared different confidence models (Rausch et al., 2018, 2020, 2023; Shekhar & Rahnev, 2021, 2024), so there is still no consensus about the computational principles underlying confidence judgments (Rahnev et al., 2022). This is problematic because meta-d′/d′ can be biased by discrimination sensitivity, discrimination criteria, and/or confidence criteria if the generative model underlying the data is not the independent truncated Gaussian model (Rausch et al., 2023). Likewise, receiver operating characteristics in rating experiments are only appropriate measures of discrimination sensitivity if the assumptions of the signal detection rating model are correct (Green & Swets, 1966; Hautus et al., 2021). At the time of writing, `statConfR` is the only available package for an open software that allows researchers to fit a comprehensive set of static models of decision confidence. The ReMeta toolbox provides Python code to fit a variety of different confidence models (Guggenmos, 2022), too, but some important models such as the independent truncated Gaussian model are missing. Previous studies modelling confidence have made their analysis scripts freely available on the OSF website (Rausch et al., 2018, 2020, 2023; Shekhar & Rahnev, 2021, 2024), but these analysis scripts are often tailored to specific experiments and require time and effort to adapt to new experiments. In addition, the documentation of these scripts is not always sufficient to be used without export knowledge in cognitive modelling. Finally, the lognormal noise model and the lognormal weighted evidence and visibility model were previously only available implemented in MATLAB, so `statConfR` makes these confidence models available to researchers who do not have access to MATLAB. The `statConfR` package also provides a faithful implementation of meta-d′/d′, which has been originally implemented in MATLAB (Maniscalco & Lau, 2012). Fleming provides MATLAB and R code for Hmetad, a Bayesian hierarchical version of meta-d′/d′ (Fleming, 2017), but notably he specifies the model slightly differently as in the original meta-d′/d′ (Rausch et al., 2023). To the best of our knowledge, there has been no open software available to estimate information-theoretic measures of metacognition up to now.

An important limitation of the models implemented in `statConfR` is that the dynamics of the decision process are not taken into account. This is a problem because confidence judgments are related to the dynamics of decision making (Hellmann et al., 2024; Pleskac & Busemeyer, 2010; Rahnev et al., 2020). However, most previously proposed dynamical models of confidence do not include a parameter to represent metacognitive ability. There is one proposal for a dynamical measure of metacognitive efficiency, the v-ratio (Desender et al., 2022), which is based on two-stage signal detection theory (Pleskac & Busemeyer, 2010), but two-stage signal detection theory has been outperformed by other models in a number of visual discrimination tasks (Hellmann et al., 2023, 2024; Shekhar & Rahnev, 2024). Thus, the static confidence models included in `statConfR` may still be useful for many researchers.

Contact

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