Preregistration Template for Application of Mathematical and Computational Models

### Metadata/Study Information

1. **Question title:** Title (required)

**Help text:** Provide an informative working title for your project. This title may change before publication. This title needs to be descriptive and specific to your project. Avoid exceedingly vague titles such as 'Decision making preregistration plan'.

**Example**: *The effect of practice and feedback on optimality in the speed-accuracy tradeoff.*

1. **Question title:** Authors (required)

**Help text:** Provide the names and order of the authors involved in this project.

**Example:** *Cora Dubrey, Fernando Crabtree, & Annette Bopp*

1. **Question title:** Description (optional)

**Help text:** Briefly describe your study, giving some information on its background and purpose. Keep this description short – while it is helpful to give some context for your project, you do not have to include a whole introductory section for the purposes of this preregistration.

**Example**: *While animals have been found to be able to reach optimality in the speed-accuracy tradeoff, the evidence for humans is mixed. It is unclear whether humans only do not act optimally by default, or whether they are unable to do so. Here, we want to investigate this issue by giving participants time to practice, and varying the amount of feedback they receive, to see if these affect whether they reach optimality in the speed-accuracy tradeoff.*

1. **Question title:** Hypotheses (required)

**Help text:** List the hypotheses to be tested. Ensure specificity, preciseness, and exhaustiveness by stating all your hypotheses/predictions as specifically and unambiguously as possible, ideally also emphasising that you will *only* be testing these hypotheses in your confirmatory analyses. Do specify if the hypotheses are directional or non-directional, and state the direction if appropriate.

**Example**: *We will test these hypotheses only:*

*H1 With suitable practice and medium feedback, participants get closer to optimality with each block of trials. (directional)*

*H2 After suitable practice and medium feedback, participants will have an approximately optimal speed-accuracy trade-off. (directional)*

*H3 Participants who complete a fixed number of trials are closer to optimality than participants who complete trials in a fixed amount of time. (directional)*

### Data Description for Pre-existing Data (delete as appropriate)

If you are using pre-existing data, please fill in this section (Questions 5-14) and ignore the sections Sampling Plan (Questions 15-18). If you are collecting the data yourself, please ignore this section and move to the Sampling Plan section.

1. **Question title:** Name or brief description of dataset(s) (required):

**Example:** *Motion discrimination task with a random dot kinematogram in 70 participants. The data used for this study is only a relevant subset of the full dataset, which includes more groups and 133 participants in total.*

1. **Question title:** Is this data open or publically available? (required) [Yes/No]
2. **Question title:** How can the data be accessed? (required)

**Help text:** Provide link if available online. Indicate any restrictions on use of the data (e.g., requires permission of the funder, law-enforcement sensitive).

**Example:** *The data are currently not openly available.*

1. **Question title:** Date of download, access, or future access: (required)

**Example**: *Accessed on 01/05/2019.*

1. 9a. **Question title:** Data Source (required)

**Help text:** Please select and describe what entity originally collected this data.

**Options:**

National Data Set – Nationally representative sample collected by another team of researchers.

Private Organizational Data – Internally collected data by an organization made available for academic purposes.

Own Lab Collection- Data were connected by one of the analysts’ lab.

Other Lab Collection – Data were collected by another researcher’s lab (analysts were not involved in data collection).

Meta-Analysis – A systematic review of published studies.

Multi-lab collaboration – Data were collected at several sites using the same procedure.

Other – Please explain

9b. **Question title:** Additional information about data source

**Help text:** If ‘other’ was selected above, please explain

1. **Question title:** Codebook (required)

**Help text:** Some studies (usually publically available) offer codebooks to describe their data. If such a codebook is available, please link to it here or upload the document.

1. **Question title:** Sampling and data collection procedures (required)

**Help text:** If the data collection procedure is already well-documented, please provide a link to the information. If the data collection procedure is not well-documented, please describe, to the best of your ability, how data were collected. What populations were sampled from, what were the recruitment efforts, what was the procedure for running participants through the study, were researchers blind to the research question, hypotheses or conditions, was randomization of any kind used, etc?

**Example:** *70 participants were recruited at the University of Newcastle and completed the experiment online, for which they received course credit. The participants were randomly (and equally) divided into the two groups of fixed trials and fixed time. The task used the random dot kinetogram, following Evans & Brown (2017) and Evans et al. (2018).*

1. **Question title:** Prior work based on the dataset (required)

**Help text:** Have you published/presented any previous work based on this dataset? Include any publications, conference presentations (papers, posters), or working papers (in-prep, unpublished, preprints) based on this dataset that you have worked on.

**Example:** *There does not exist prior work based on this dataset.*

1. **Question title:** Prior Research Activity (required)

**Help text:** Have you worked with these data before? Describe any prior but unpublished research activity using these data in a specific and transparent way.

**Example:** *We have used all of these variables & some of these models before on this (sub)set of data.*

1. **Question Title:** Prior knowledge of the current dataset (required)

**Help text:** Describe any prior knowledge of the dataset. Be as specific as possible.

**Example:** *We have already fit the model from Figure 1 [not included here] to the data and checked the results from one of the groups that are not relevant for the current study, and has run the model-based analyses using the model in Figure 2 [not included in example] and here also checked the consistency of the Bayes factor approximation for one of the irrelevant groups.*

### Sampling Plan (if own data collection) (delete as appropriate)

If you are using pre-existing data, you may delete this section.

1. **Question title:** Data collection procedures (required)

**Help text:** Please describe your data collection process. If you are using human subjects, this should include the population from which you obtain subjects, recruitment efforts, payment for participation, how subjects will be selected for eligibility from the initial pool (e.g. inclusion and exclusion rules), and your study timeline. For studies that do not include human subjects, include information about how and for how long samples will be collected, the source or location of samples, and/or the batch numbers you will use.

**Example**: *Participants will be students recruited through advertisements at a university, where they will receive course credit for their participation.*

1. **Question title:** Sample size (required)

**Help text:** Describe the sample size of your study. How many units will be analyzed in the study? If the units are not individuals, then describe the size requirements for each unit. Either state exact numbers or an expected range.

**Example**: *Our target sample size is 70 participants. We will attempt to recruit up to 90, to allow for exclusions.*

1. **Question title:** Sample size rationale (optional)

**Help text:** This could include an arbitrary constraint such as time, money, or personnel, power analysis, or an analysis based on a parameter recovery study. This gives you an opportunity to specifically state how the sample size will be determined. A wide range of possible answers is acceptable; remember that transparency is more important than principled justifications. Any pre-specified reasoning behind the sample size is preferable to ambiguity and potential confusion for the reader.

**Example**: *The number of subjects is based on a parameter recovery study.*

1. **Question title:** Stopping rule (optional)

**Help text:** If you cannot pre-specify your sample size, specify a stopping rule, i.e., how you will decide when to terminate your data collection. Unacceptable rationales include stopping based on p-values if checkpoints and stopping rules are not specified. If you have control over your sample size, then including a stopping rule is not necessary, though it must be clear in this question or a previous question how an exact sample size is attained.

**Example**: *We will post participant sign-up slots by week on the preceding Friday night, with 20 spots posted per week. We will post 20 new slots each week if, on that Friday night, we are below 320 participants.*

### Design Plan

In this section, you will be asked to describe the experimental design of your study. Remember that this research plan is designed to register a single study, so if you have multiple experimental designs, please complete a separate preregistration. Note that this is about experimental design; your modelling design choices will be registered in a later section.

1. **Question Title:** Study type (required)
2. Experiment - A researcher randomly assigns treatments to study subjects, this includes field or lab experiments. This is also known as an intervention experiment and includes randomized controlled trials.
3. Observational Study - Data is collected from study subjects that are not randomly assigned to a treatment. This includes surveys, natural experiments, and regression discontinuity designs.
4. Other - Please elaborate.
5. **Question Title:** Blinding (required)

**Help text:** Blinding describes who is aware of the experimental manipulations within a study. Mark all that apply.

1. No blinding is involved in this study.
2. For studies that involve human subjects, they will not know the treatment group to which they have been assigned.
3. Personnel who interact directly with the study subjects (either human or non-human subjects) will not be aware of the assigned treatments. (Commonly known as “double blind”)
4. Personnel who analyze the data collected from the study are not aware of the treatment applied to any given group.
5. **Question title:** Is there any additional blinding in this study?
6. **Question title:** Experimental design (required)

**Help text:** Describe your experimental design. This question has a variety of possible answers. The key is for a researcher to be as detailed as is necessary given the specifics of their design.

**Example**: *We have a 3 (feedback: low, medium, high) by 2 (fixed time, fixed trial) by 23 (practice block) design.*

1. **Question title:** Randomization (optional)

**Help text:** If you are doing a randomized study, how will you randomize, and at what level? If randomization is required for the study, the method should be specified here, not simply the source of random numbers.

**Example:** *We will use block randomization, where each participant will be randomly assigned to one of the four equally sized, predetermined blocks. The random number list used to create these four blocks will be created using the web applications available at http://random.org.*

### Variables

In this section you can describe all variables that are manipulated and measured in your experiment.

1. **Question title:** Manipulated variables (optional)

**Help text:** Describe all variables you plan to manipulate and the levels or treatment arms of each variable. This is not applicable to any observational study. For any experimental manipulation, you should give a precise definition of each manipulated variable.

**Example:** *We manipulated the level of feedback given to participants, and whether they completed trials in a fixed amount of time, or a fixed number of trials.*

1. **Question title:** Measured variables (required)

**Help text:** Describe each variable that you will measure. Observational studies will include only measured variables. As with the previous questions, the answers here must be precise.

**Example**: *The outcome variables measured are reaction time in seconds and response accuracy in percent correct.*

1. **Question title:** Indices (optional)

**Help text:** If any measurements are going to be combined into an index (or even a mean), what measures will you use and how will they be combined? Include either a formula or a precise description of your method. If you are using multiple pieces of data to construct a single variable, how will this occur? Both the data that are included and the formula or weights for each measure must be specified. Standard summary statistics, such as “means” do not require a formula, though more complicated indices require either the exact formula or, if it is an established index in the field, the index must be unambiguously defined. For example, “biodiversity index” is too broad, whereas “Shannon’s biodiversity index” is appropriate.

**Example**: *For each cell and each individual, we will calculate mean response time and accuracy.*

### Data Cleaning and Preparation

1. **Question title:** Data exclusion (required)

**Help text:** How will you determine what data (e.g., participants or trials), if any, will be excluded from your analyses? How will outliers be handled? Will you use any awareness checks? Any rule for excluding a particular set of data is acceptable. You may describe rules for excluding a participant and/or for identifying outlier data.

**Example**: *For all participants, the first block of trials will be excluded to allow for participants to become adequately practiced at the task. Trials with response times below 150ms or above 10000ms will be excluded as anticipatory responses and trials where participants lost attention, respectively. Participants with task accuracy below 60% or less than 200 eligible trials (based on the number of trials required for accurate parameter estimation) will be excluded.*

1. **Question title:** Missing data (optional)

**Help text:** How will you deal with incomplete or missing data? Any relevant explanation is acceptable. As a reminder, the final analysis must follow the specified plan, and deviations must be either strongly justified or included as a separate, exploratory analysis.

**Example**: *If a subject does not complete the entire duration of the experiment, that subject will not be included in the analysis.*

1. **Question title:** Data Partitioning for Train/Test (optional)

**Help text:** What is your method for splitting the data? Specify the number of split datasets that will be created and the relative size of each. If this preregistration document is being used in the middle of a training/testing cycle, specify where you are currently in that process.

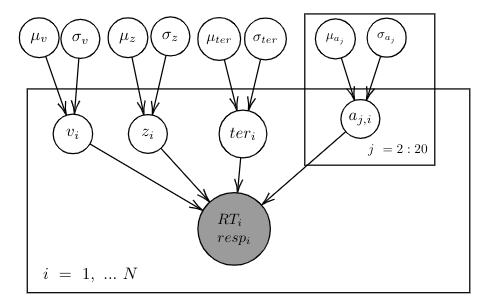
**Example:** The total N will be randomly split into three portions. The first 10% will be used initially for the training dataset, the next 40% will be used for the first validation and model refinement. The final 50% will be held off for the final test. A new preregistration will be created between each subsequent cycle. After the final iteration, the results will be completely reported as pre-specified, and any further model refinement will be labeled as “exploratory” to be tested with additional, future datasets.

### Modelling

1. **Question title:** Mathematical or Computational Model (Required)

**Help text:** Please describe the type of model used here and its architecture, including constructs/variables, relationships, and parameters. Please state the intended function or purpose of the application of this model. State the type of model used (e.g., diffusion model, linear ballistic accumulator model, production system). If the model employs Bayesian methods/inference, define and justify the priors.

For clarity and completeness, please, attach or link to formulae, plate diagrams, machine readable representation of the model, or other useful materials (i.e. code, documentation, relevant publications).

**Example:** *The parameters of a simple diffusion model will be estimated, namely only: drift rate (v), starting point (z), threshold (a), non-decision time (ter). This differs from [previous paper], where the full diffusion model was estimated, i.e., including between-trial variability parameters for drift rate, starting point, and non-decision time. These between-trial variability parameters are not relevant here, and without them, the simple diffusion model has better parameter recovery results (Lerche & Voss, 2016). Figure 1 shows a plate diagram of the hierarchical structure used for the qualitative model-based analysis assessing 1) whether groups appear to get closer to optimality over time, 2) whether each group differs from optimality, and 3) whether there appears to be a difference between the groups (see Analysis Plan for more information); i indexes participants, and j indexes blocks. Only the threshold parameter varies between blocks, to estimate changes in the speed accuracy trade-off.*

*Figure 1. Plate diagram of the hierarchical structure used. RT stands for reaction time, resp stands for response accuracy.*

*The parameters of the estimation model shown in the plate diagram of Figure 1 are distributed as: [include specific distributions, e.g. at data level and group level, and the relevant prior distributions]*

1. **Question title:** Method of Parameter & Hyperparameter Estimation (Required)

**Help text:** Please specify and justify your method of estimating the values of parameters and hyperparameters. If you are going straight to statistical inference without estimating the parameters, please state this clearly and motivate this choice. If parameters are not estimated because existing parameter values are used, state this clearly. In general, specify as much as possible, including e.g. the starting point (distribution) or any initial values for starting the estimation procedure. Ideally, include other useful resources such as the code used (including language/program, version, and the name of the specific fitting algorithm or function used). Specify whether any summary statistics will be computed on the parameterised model. These might be at the level of the model (model fit statics, e.g. AIC, BIC, log-likelihood), at the level of the parameter estimate, at the model-observation level (i.e. including any diagnostics of fit quality), or at the model-estimate level.

**Example:** *Only Bayesian hierarchical modeling will be used to estimate the parameters of the diffusion model, constraining individual-level parameters to follow group-level truncated normal distributions. For the estimation model (see Figure 1, the two groups (fixed-trial and fixed-time) are given a separate hierarchical structure, and the group-level parameters are not constrained between groups. We will use likelihood functions taken from the ``fast-dm'' toolbox (Voss & Voss, 2007) for the calculation of the density function of the simple diffusion model. For the first model, for sampling from the posterior distributions over parameters, we will use Markov-chain Monte Carlo with differential evolution proposals (Turner et al., 2013), using 66 chains, drawing 3,000 samples from each, and discarding the first 1,500 samples.*

**More information:**

### Robustness Checks and Model Testing

1. **Question title:** Robustness Checks and Sensitivity Analyses (Required)

**Help text:** Please specify any planned robustness checks, model testing, and/or sensitivity analyses, if any. For each check, test, or analysis you perform, please specify the metric or threshold under which the model passes or fails. Clearly motivate your choice of analysis and metric. Provide any code, or other resources where available. This section ensures that robustness checks are not performed and/or reported selectively. It is important to note that, given the preregistration of modelling and analyses, it should be clear that any lack of robustness is not due to post-hoc, data-driven choices. Justifications for use of a particular method over others should be well-reasoned.

***Example:*** *The key analysis will be replicated a) including participants/trials that were initially excluded in line with our exclusion criteria, and b) using a model in which the threshold parameter and the drift rate parameter vary across blocks. Their results will be mentioned alongside the key results, and interpreted accordingly. If these results show a lack of robustness, this will be an interesting outcome worthy of further investigation.*

### Analysis Plan

Please specify at least one confirmatory analysis. The confirmatory analyses described here have to be included in the final article, with a clear distinction from any additional exploratory analyses. This preregistration must state up front which parameters are assessed, for example to vary across conditions. Only then is it a confirmatory analysis, otherwise it is exploratory. You may describe exploratory plans here, but a clear confirmatory analysis is needed.

1. **Question title:** Statistical Analyses (required)

**Help text:** Specify the methods that will be used to test each hypothesis as precisely as possible. In particular, specify the method(s) and process(es) of (statistical) inference and on which parameters of interest you will be applying them. In the case of model-based analyses, make sure to also include the relevant models in the Modelling section above. Keep in mind that any analyses not mentioned and specified in these confirmatory sections must be clearly labeled as exploratory in the final output. As with all of the other questions, the key is to provide a specific recipe for analyzing the collected data. Ask yourself: is enough detail provided to run the same analysis again with the information provided by the user?

**Example**: *Our hypotheses will be quantitatively tested by means of only the following tests:*

*Testing H2: Using only the second half of all 20 blocks (11-20, so as to account for participants adjusting to the task), we will test whether each group, separately, differs from optimality using Bayes factors, approximated with the Savage-Dickey Ratio on 𝜇c.*

*Testing H3: Again using only blocks 11-20, we will use the Savage-Dickey method on 𝛥c (𝛥c = 𝜇c1 - 𝜇c2) to test whether the groups differ in their distance from optimality.*

1. **Question title:** Other analyses (optional)

**Help text:** Specify any other confirmatory analyses you intend to perform.

**Example:** *Testing H1/2/3: In addition to the statistical analyses listed above, we will qualitatively compare the posterior distributions of the decision threshold parameters (actual thresholds for each block as estimated using the model in Figure 1) against the posterior predictive distributions for the optimal threshold calculated as above.*

1. **Question title:** Inference criteria (optional)

**Help text:** What criteria will you use to make inferences? Please describe the information you will use (e.g. p-values, Bayes Factors, etc.), as well as a cut-off criterion, where appropriate. Will you be using one or two tailed tests for each of your analyses? If you are comparing multiple conditions or testing multiple hypotheses, will you account for this?

**Example**: *These are the inference criteria for our analyses listed above:*

*1. Criterion for BF testing H2: Following Jeffreys (1961) for the interpretation of strength of evidence given a Bayes Factor. If c = 0, the behaviour of the group is optimal, if c < 0 it is urgent, and if c > 0 it is cautious.*

*2. Criterion for BF testing H3: Following Jeffreys (1961) for the interpretation of strength of evidence given a Bayes Factor. If 𝝙c = 0, the groups are the same regarding their difference from optimality, and if 𝝙c < 0 or 𝝙c > 0, the groups differ in their distance from optimality.*

*3. Criterion to test H1, qualitatively evaluating the plots comparing posterior to posterior predictive distribution: If the actual thresholds of both (or one) group(s) clearly show a trend towards optimality, we will conclude that participants move towards optimising the speed-accuracy trade-off. Otherwise, our conclusion will be suitably less strong and discuss any lack of clarity.*

1. **Question title:** Exploratory analysis (optional)

**Help text:** Describe any exploratory analyses you expect to do. An exploratory test is any test where a prediction is not made up front, or there are multiple possible tests that you are going to use. A statistically significant finding in an exploratory test is a great way to form a new confirmatory hypothesis, which could be registered at a later time. It is crucial to clearly distinguish confirmatory from exploratory results in your final article.

**Example**: *We are currently not planning any exploratory analyses.*

### Other

1. **Question title:** Other (Optional)

**Help text:** Any other information not included in the above. You may include e.g., literature cited, disclosures of any related work such as replications or work that uses the same data, or other context that will be helpful for future readers and/or yourself.