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PSYC03H3

Computers in Psychological Research: Advanced Topics

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April 2022

**Exploring Order Effects: Scripts for Psychtoolbox, 2D Hilbert Space, and Quantum-Question-Equality Normalisation**

Measurements in psychological experiments often appear noisy and have inconsistent rest-retest reliability. Participants seem to react disproportionately to small changes in context, such as the order of questions or stimuli, posing a challenge to data analysis. Fortunately, there seems to be hope from a relatively new type of *zero-parameter* analysis (Wang & Busemeyer, 2014; Busemeyer & Wang, 2018; Ozawa & Khrennikov, 2021), that suggests that inconsistencies are not entirely due to noise, that the change in perspective caused by context can be modelled in a rotational space. The following is an exploration of the simplest case of context effects: order effects in 2x2 chi-squares using a famous data set from social psychology: the Al Gore – Bill Clinton survey from the late 90’s, when President Bill Clinton was notoriously untrustworthy, especially when compared to the upstanding Al Gore, meaning that survey answers heavily depended on question order.

This project has been arranged as a future reference, containing the following 5 scripts:

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| **AGBC.m (Psychtoolbox)**  A standard psychtoolbox data collection script that outputs data as a txt file with a random 32bit identifier, for easy import into non-MATLAB programs. **AGBC\_datautil.m** aggregates the txt data |

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| **AGBC\_PCA.m**  Runs a PCA analysis on the real data rounded to 200 participants. Chart, bar chart  Description automatically generated Chart, bar chart  Description automatically generated  % COEFF\_mat =  %  % 0.7240 0.0974 0.6829  % 0.6510 -0.4241 -0.6296  % 0.2283 0.9004 -0.3704  With order included, PC2 actually depends heavily on question order. |

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| **make2xstoch.m**  All three cited papers explain how to model order effects quantumly (Wang & Busemeyer, 2014; Busemeyer & Wang, 2018; Ozawa & Khrennikov, 2021), but as a brief introduction, it is like doing probability with Pearson’ R2 in a special spherical space, or doing a change of basis for the perspectives of each question. Unlike in Euclidean space, opposite answers are represented as being 90 degrees apart rather than as distant points in a single dimension.    The spherical symmetry of the space means that a *zero-parameter* symmetry called the Quantum-Question-Equality (QQE) can be predicted, where the opposite sides of a chi-square table must add up in a specific way. The underlying principle is called “double stochasticity”, an additional restriction that modelling a participant’s perspective in Hilbert Space has that Euclidean space does not. Shown below is a diagram with another famous data set. This script generates doubly-stochastic chisquare table based on 2D Hilbert Space.    Given any a and b:  % y1n2 = cos(a)\*cos(b);  % n2y1 = sin(a+b)\*cos(b);  % n1y2 = sin(a)\*cos(b);  % y2n1 = cos(a+b)\*cos(b);  % y1y2 = cos(a)\*sin(b);  % y2y1 = sin(a+b)\*sin(b);  % n2n1 = cos(a+b)\*sin(b);  % n1n2 = sin(a)\*sin(b);  A sample output:  % make2xstoch(70, 50)  %  % chisq1 =  %  % 0.0686 0.0483  % 0.3648 0.5182  %  %  % chisq2 =  %  % 0.4401 0.3099  % 0.1033 0.1467  %  %  % chisq3 =  %  % 0.2544 0.1791  % 0.2341 0.3324  Through testing, I found that the AGBC chisquare table cannot be found here, meaning that it is 3D or higher. |

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| **qqe\_correction.m** is my attempt at a partial-replication Ozawa & Khrennikov (2021) that details a method of normalising based on another *zero-parameter* analysis, that purportedly predicts the percentage of individuals of 3 personality types: those who retain their starting perspective, those who prefer to swap answers between questions, and those who like to give the same answer to both questions (q0,q1,q2). Notably the analyses uses only standard Bayesian Using these values,  q0 = .6045; % unaffected by order effects  q1 = .0668; % affected: likes to swap answers  q2 = .3288; % affected: likes to repeat answers  realAy = (p11+p10) %.5339 vs Ay=.5613  realBy = (p11+p01) %.7613 vs By=.7141  The results are a roughly 4% adjustment to perceived trustworthiness can be considered normalised, a significant adjustment that can affect PCA and other analyses. |

Busemeyer, J. R., & Wang, Z. (2018). Hilbert space multidimensional theory. *Psychological Review*, *125*(4), 572–591. <https://doi.org/10.1037/rev0000106>

Ozawa, M., & Khrennikov, A. (2021). Modeling combination of question order effect, response replicability effect, and QQ-equality with quantum instruments. *Journal of Mathematical Psychology*, *100*, 102491. <https://doi.org/10.1016/j.jmp.2020.102491>

Wang, Z., Solloway, T., Shiffrin, R. M., & Busemeyer, J. R. (2014). Context effects produced by question orders reveal quantum nature of human judgments. *Proceedings of the National Academy of Sciences*, *111*(26), 9431–9436. <https://doi.org/10.1073/pnas.1407756111>