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Review of Doctoral Dissertation of Kamil Bonna, MSc

**Title of Dissertation: Neural correlates of prediction errors
during reward and punishment learning**

**Supervisor: prof. dr hab. Włodzisław Duch, Faculty of Physics,
Astronomy and Informatics, Nicolaus Copernicus University in Torun**

The dissertation submitted for evaluation by Mr Kamila Bonna deals with the study of postulated prediction systems in the human brain with the initial experimental methods in the form of functional magnetic resonance imaging (fMRI). Predictive systems are related to learning by trial and error. The principle of operation is relatively simple - a successful prediction corresponds to obtaining a reward, so that the behaviours, thanks to which the results were predicted, are favoured and strengthened, while the actions related to the prediction of the effect opposite to the real effect are related to the representation of the penalty, by those weakened, as a result of which in repeated conditions are avoided.

The author of the dissertation combines three complementary methods of the probabilistic learning approach:

- behavioral,
- localisation,

- network based.

The author conducted a whole-brain analysis which let him indicate the brain regions involved in the process mentioned above by revealing multi-scale community structures in topological aspects. The patterns, that are worth to be mentioned followed the predictions of the Global Workspace Hypothesis.

Taking the above into consideration, I do believe that the choice of subject is right and actual.

The work is presented in the English language and has 137 pages. The main part consists of four chapters. The text also has an abstract, table of contents, list of figures, list of tables and acknowledgements in the beginning and the references and one appendix at the end. The literature section lists 362 not numbered items. Section Introduction and Summary nicely embrace the content of the thesis which makes the dissertation comfortable to read and follow.

In Chapter 1 the author presents general ideas of reinforcement learning. As usual, the first chapter of each dissertation consists of a theoretical introduction and presents the current state of the art.

In Chapter 2 we are gently introduced to the methods and current state of the art in the field of methods used for neuroimaging the prediction errors.

In Chapter 3 we are offered some cognitive set of theories, called "Network Neuroscience", their functionalities as well as ideas of small worlds, hubs and scale-free networks. In Chapter 3 it is proved that the author has a meaningful impact on the whole theory and it is presented in two of his co-authored papers:

- Finc, K., Bonna, K., He, X., Lydon-Staley, D. M., Kuhn, S., Duch, W., and Bassett, D. S. (2020). Dynamic reconfiguration of functional brain networks during working memory training. *Nature communications*, 11(1):1–15.
- Finc, K., Bonna, K., Lewandowska, M., Wolak, T., Nikadon, J., Dreszer, J., Duch, W., and Kuhn, S. (2017). Transition of the functional brain

network related to increasing cognitive demands. Human brain mapping, 38(7):3659-3674.

often cited there.

It is worthwhile to notice that the Applicant has six articles listed in Google Scholar and an h-index of 5.

The most important part of the dissertation is Chapter 4. It is in this chapter where hypotheses are stated:

- Two separate systems are involved in Prediction Errors processing.
- Prediction errors are rescaled by agents according to their reference effect.
- Large-scale networks increase their integration during negative prediction error processing.

In the following pages, author verifies those hypotheses and a wide variety of tools are used in his approach: Markov Chains, Bayesian modelling, two-level GLM for model-based fMRI and functional analysis of brain networks existence of which is postulated by the author.

In the paragraph 4.7 we can find a discussion with the verification of hypotheses summary, which leads to the following findings broadly described in 4 subsections:

- Opponent system for negative prediction errors processing.
- Brain systems are organized along prediction error sign axis.
- Negative prediction errors elicits stable pattern of network reconfiguration.
- Ventromedial prefrontal regions form separate network during positive prediction error processing.

The whole dissertation is written in very good-style English language, edited in L^AT_EX which is visible due to its perfectionism and lack of technical, and editorial errors.

Critical remarks

As a reviewer I must note some critical remarks.

- In my opinion, hypotheses appear too late in the text. Readers ought to be informed much earlier about what the goal of the thesis/dissertation/project/paper is.
- The works presented by the author has a very interdisciplinary context so the list of shortcuts could be added somewhere at the beginning of the dissertation.
- I would read with high interest some section concerning future plans, especially whether the author considers using some other neuroimaging techniques, i.e., 7T ultra-high-field fMRIs that start to appear in Poland and – in my opinion – to obtain better temporal resolutions for some EEG measurements by developing ERP (Event-Related Potentials) experiments.

All of the above-mentioned remarks have only a technical character and do not influence my generally positive impression of Mr. Bonna's PhD thesis.

Recommendation

In my opinion, the presented dissertation has significant scientific value for physics, biomedical engineering, general neuroscience and computer science.

The reviewed research required not only broad cognitive knowledge but also the knowledge of the most advanced methodologies of big data engineering and

data science in physical applications.

That is why I do believe that the presented dissertation meets the conditions for the degree of doctor of physical sciences and apply for the Dean and the Honorable Commission to accept it for further stages of doctoral conferment procedures.

To sum up: In my opinion this thesis satisfies all the usual and formal demands set out for doctoral theses and I strongly support awarding doctoral degree to Mr Kamil Bonna. [Uważam, że rozprawa doktorska mgr. Kamila Bonny spełnia warunki określone w art. 187 Ustawy z dnia 20 lipca 2018 r. o szkolnictwie wyższym i nauce (Dz. U. 2018 poz. 1668), dlatego zwracam się do Wysokiej Rady Dyscypliny Nauki Fizyczne Uniwersytetu Mikołaja Kopernika o dopuszczenie mgr. Kamila Bonny do dalszych etapów przewodu doktorskiego.]

A handwritten signature in blue ink, reading "Grzegorz Mochnik Wójcik". The signature is written in a cursive, flowing style.

Lublin, 2022-06-03