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Review report on the dissertation thesis “Prediction, Learning and Signal Integration in the Sense of Agency” of Bartosz Majchrowicz submitted to Jagiellonian University in Krakow

The thesis submitted by Bartosz Majchrowicz addresses a fundamental question regarding the nature of the human mind: What are the cognitive and neural processes that support the human sense of agency, the feeling of having control over one’s own actions? The thesis builds on previous work in Cognitive Neuroscience and Experimental Psychology, reviewed in the introduction of the thesis. This work uses a variety of subjective and objective measures to address a variety of mechanisms that could support the sense of agency: integration of sensory signals, predictive and inferential processes, and learning. The thesis reports three empirical studies (seven experiments using behavioral and neurophysiological measures) that contribute to a better understanding of the processes supporting the sense of agency and the measures used to study it. All three studies have already been published in internationally recognized experimental psychology journals that implement a rigorous peer review process addressing theoretical relevance and appropriateness of methodology of each submitted manuscript. Bartosz Majchrowicz is the lead author for all three publications.

Study 1

The first study, published in ‘Consciousness and Cognition’, addresses the question of whether explicit and implicit measures of the sense of agency diverge when an action has unexpected consequences. According to prominent models postulating that the sense of agency relies on predictive processing, both measures should show a reduction in the sense of agency if something unexpected happens after performing a movement. A variant of the classical Libet task was used to test this prediction. Intentional binding was used as an implicit measure for the sense of agency: the perceived time between movements and events is compressed when an event is intended to follow a movement. As explicit measure of the sense of agency a 5-item questionnaire was used: participants were asked to report how much control they felt over expected and unexpected events after completing each of three parts of the experimental.

The results for the explicit measure were as predicted, sense of agency was reduced for unexpected events. Surprisingly, intentional binding was larger for unexpected events. This general pattern was replicated across three experiments that varied such parameters as the temporal delay between movement and unexpected outcome, and whether participants encountered unexpected events during the initial phase of the experiment, where a baseline for the perceived time of movements and events was established.

The discussion of the results is very competent and balanced. However, it does not take a clear position in flashing out the main implications of the study. One bold way of summarizing the main finding would be that the robust effect of increased intentional binding for unexpected action outcomes across three experiments invalidates intentional binding as a measure of the sense of agency. Alternatively, one could conclude that the sense of agency is higher when the outcomes of an action are unexpected, disregarding the explicit measures. The general issue here is whether the results of the study should be taken to imply that the sense of agency is ultimately a subjective experience that needs a subjective report/measure as a reference or whether we should discard people's experience as much as possible and move on using implicit measures of agency. In any case, the results of the study certainly have important implications for interpreting future studies that use intentional binding as a measure of the sense of agency.

One potential issue with the study is the use of a questionnaires as an explicit measure of agency. Most previous studies asked participants to report their feeling of agency immediately after their action caused an effect (or not). This decision resulted from a concern that frequently asking participants about their sense of control may cause demand characteristics. This is a valid concern. However, asking about the sense of agency in a questionnaire that is completed after each part of the experiment seems to introduce a whole host of other problems. There is ample research demonstrating that increasing the delay between a sensory/perceptual experience to be reported and the actual time of the report leads to an increase in interpretations/confabulations (e.g., in wine tasting). Isn't this reactivity of delayed subjective reports even more worrying and harder to control than potential demand characteristics? I wonder whether one would expect larger correlations between implicit and explicit measures of the sense of agency for explicit measures obtained without delay in each trial?

Study 2

The second study, published in 'Quarterly Journal of Experimental Psychology', addresses the link between learning and the sense of agency. Previous research indicates that the sense of agency is enhanced for negative outcomes that will help improve future performance (learning). The first experiment of the present study tested whether such enhancements are task- specific. Using a task switching procedure that involved repeating the same task as well as switching between different tasks, it was established that

encountering a negative action outcome enhanced the sense of agency in the consecutive trial when the task remained the same. However, there was no enhancement of the sense of agency in the ensuing trial when the task switched. This finding clearly supports the claim that the sense of agency is only enhanced when negative action outcomes support learning. The second experiment asked whether being able to freely choose which actions to perform is a precondition for the enhancement. The results showed that only negative outcomes of a freely chosen action enhanced the sense of agency in the ensuing trial regardless of whether participants were able or not to choose between different actions in this trial. Two event-related potentials derived from the EEG, the FRN and the P300 provided converging evidence for the interpretation that the sense of agency is enhanced when negative outcomes result from freely chosen actions and are relevant for mastering the task at hand.

The idea of using a task switching procedure, to determine how the informative value of negative feedback affects the sense of agency, is clever and innovative. Regarding the implementation, I was wondering whether the results would have been even more convincing had a more standard task switching procedure been used. In this procedure, the same stimuli require different responses under different task mappings, for instance, Task A is to report whether a number is larger or smaller than 5, Task B is to report whether a number is odd or even. Applying this standard procedure allows one to change a task set without any confounds such as a change in stimuli between the two tasks. The way task switching was implemented in the present experiment it seems not entirely clear whether the switch in task set, the switch in stimuli, or both together disrupted the enhancement for the sense of agency in the consecutive trial.

In the general discussion the results of the study are linked to psychopathological conditions such as learned helplessness. Creating such links is very interesting and demonstrates the real world impact that studies of the sense of agency may have. However, it did not become entirely clear to me from the short mention, exactly how the current results could explain learned helplessness and passivity phenomena. A little bit more detail would have helped here but I hope that there will be a chance to discuss this a further during the defence.

Study 3

The third study, published in 'Consciousness and Cognition', addresses sensory attenuation, which is related to the sense of agency. The key finding here is that the predicted sensory consequences of one's own movements are perceived at lower intensity (e.g., one cannot tickle oneself). However, recent studies found indications that sensory attenuation may depend on the general intensity level of the stimulation and the valence of the stimulus. In the present study two experiments varied the intensity and valence of auditory stimuli to test how sensory attenuation is modulated by these factors. The surprising finding was that there was sensory enhancement for the sensory consequences that followed participants' own movements (compared to passive perception). These enhancements were most

pronounced for stimuli of low intensity and positive valence. These results indicate that sensory attenuation for the sensory consequences of own movements may be a less stable phenomenon than was previously thought. Whether a sensory experience is attenuated or enhanced seems to depend on moderating factors including the intensity of stimulation and the affective component of the sensation.

A potential issue with this study is that the use of an intensity rating instead of more established measures for sensory attenuation may have tapped into a different level of processing than the standard measures. Sensory attenuation is often described as a very fundamental aspect of sensory processing that has a direct effect on people's experience (e.g., in the tickling example). Could it be that subjective measures are not sensitive enough to tap into the relevant systems and reflect perceptual experiences at a level where the raw sensory experience has already passed on to a stage where additional cognitive and affective processing has taken place? Would this explain the somewhat surprising results?

Conclusion

The three studies reported in the thesis make a very substantial and original contribution to research on the sense of agency, a key topic in Cognitive Science and Cognitive Neuroscience. Each study has been subject to rigorous peer review and was published in an internationally recognized journal. Each study has a strong theoretical motivation and clear results. The experiments are well designed and comply with high methodological standards. The results are analyzed appropriately, and they are interpreted in a balanced manner. Personally, I think that stronger conclusions could have been drawn from some of the results. However, this is a matter of style, and it was probably wise to stay on the more cautious side. There could have been a little bit more integration, tying together the general implications from the three studies. Taken together, this is an impressive piece of work that more than meets international criteria for awarding a PhD degree in my field.

A handwritten signature in blue ink, appearing to read 'G. Knoblich', written on a light-colored background.

Günther Knoblich
Professor of Cognitive Science