Trends in Cognitive Sciences

CellPress
REVIEWS

Spotlight

Learning from Others, but with What Confidence?

Alireza Soltani[1,*]

A recent study by Zhang and Gläscher (2020) in humans examines learning from one's own versus others' actions under reward uncertainty. Comparing findings from this and non-human studies on learning under perceptual uncertainty suggests a unified role for confidence in learning under different types of uncertainty across mammalian brains.

Imagine driving down a highway during heavy rain when you have to constantly adjust your speed based on how well you can control your car. A few minutes later when the rain is over, you see cars in front of you slowing down (perhaps due to an accident) and some are exiting the highway to avoid traffic. You then start deliberating whether you should exit or not. Although you are learning from your actions versus others', in both cases – deciding how fast to drive and deciding whether to exit – you make predictions about the uncertain world and adjust these predictions based on your confidence in your choices with little feedback.

Confidence in our choices could modulate how much we learn from each feedback or without any feedback [1]. However, proper use of confidence requires incorporating feedback from the environment to adjust our confidence or we end up with dogma (Figure 1). But to what extent, do similar mechanisms support the interaction between learning and confidence in social versus nonsocial settings?

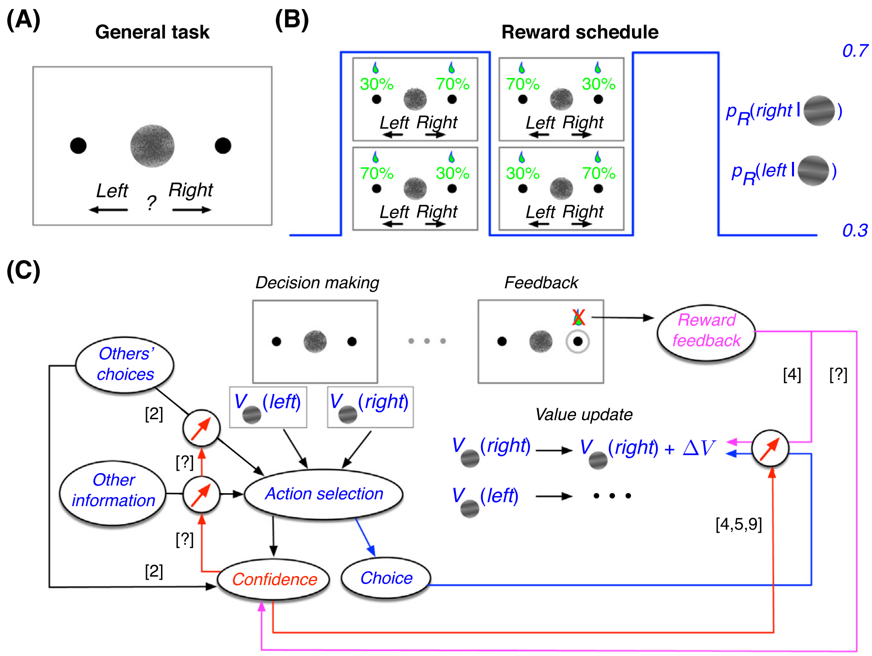
Recently, Zhang and Gläscher [2] extended a nonsocial learning paradigm known as probabilistic reversal learning (PRL) to examine how learning from others is integrated with learning from oneself and the role of confidence during this process. In their task, five participants simultaneously chose between two stimuli that provided rewards with complementary probabilities, with the probabilities assigned to the stimuli switching every 8–12 trials. After each participant made their choice and reported their confidence (by placing a bet), they observed what the other participants had chosen and were allowed to adjust their choice (and bet) before receiving reward feedback. This allowed the authors to examine how observing others' decisions influenced the participant's choice, confidence, and subsequent learning. The authors found that participants' choice accuracy and the amount they bet increased after seeing others' decisions. In addition, when participants stayed with the stimuli they originally selected or switched their selection, increase in accuracy and bet were larger with larger group consensus.

To reveal underlying mechanisms, Zhang and Gläscher [2] fitted the data using multiple computational models. In the best-fitting model, subjective values of options were a linear combination of two separate learning systems: participants' estimates of reward probabilities (direct learning) and discounted cumulative reward history for group members (social learning). Using brain imaging, they identified neural correlates of direct and social learning systems in ventromedial prefrontal and anterior cingulate cortex (ACC), respectively, and these signals seemed to interact via the putamen (Put). They also found representations of reward prediction error (RPE = difference between expected and actual reward) in ventral striatum/nucleus accumbens as well as a novel social prediction error (SPE = difference between actual and expected group consensus) in the left-Put. At a mechanistic level, variants of RPE can be used for volatility estimation and learning adjustment, whereas variants of SPE can be used to determine the weight of social information on the overall value, as suggested by models of learning under uncertainty [3].

These results show parallels with those of other studies examining the role of confidence in learning in nonsocial settings and under perceptual uncertainty. For example, Sarafyazd and Jazayeri [4] trained monkeys to first report the current rule of a task, which could reverse unpredictably, and then make a choice based on a sample time interval and the current rule (e.g., make a pro- or antisaccade if the interval is shorter/longer than a specific value). They showed that a confidence-based switch model, in which the animal updates evidence for a switch in rule on each error trial based on the expected accuracy of the previous trial, could account for their data. Moreover, using single-cell recording and microstimulation, they demonstrated that ACC represents cumulative switch evidence and is crucial for switching behavior. Evidence for switching from the current rule is similar to adjustments in choice according to group consensus, and the role of ACC in both computations is intriguing.

Using PRL under perceptual uncertainty, a recent study in rats also demonstrated that ACC is crucial for confidence computation and that benefits of confidence for learning disappear or reverse with inhibition of ACC [5]. It has been suggested that ACC's contributions to confidence computation stem from its ability to integrate reward and error on long timescales [4,6,7]. ACC can also integrate choice outcomes on longer timescales than other cortical areas implicated in reward and choice processing [8]. This finding is significant because the history of ones' choices could be used to determine confidence in both nonsocial and social settings.

CellPress
REVIEWS



Trends in Cognitive Sciences

Figure 1. Role of Confidence in Learning under Uncertainty. (A, B) Schematic of a general task for learning under uncertainty. Participants choose between two actions (go left vs right) upon observing an ambiguous sensory stimulus while reward contingencies change unpredictably between blocks of trials. (C) Values associated with different actions and other sources of information are combined to make decisions and yield confidence readout. Values are updated based on choice and reward feedback. Value updates could be modulated by confidence while reward feedback can adjust confidence. Numbers and the question marks in brackets indicate specific studies examining each contribution and unexamined links see [2,4,5,9].

Finally, Lak and colleagues demonstrated that across mammalian species, perceptual choice is influenced by confidence (difficulty of judgment) in the previous trial such that psychometric function is shifted toward the previously chosen side more strongly if the previous trial was more difficult [9,10]. They explained this observation by assuming the subjective value of the chosen option is multiplied by sensory confidence. It is yet to be determined how confidence in others' choices modulates the weight of others' experiences on the overall subjective value. Nonetheless, confidence can provide missing gradedness for learning from binary reward feedback and modulate learning of subjective values when there are other sources of uncertainty (Figure 1C).

Observing others' choices changes our confidence and future learning. Although Zhang and Gläscher [2] did not find neural correlates of confidence, they observed positive and negative correlation of left-Put activity with actual and expected consensus (i.e., SPE). SPE could provide the missing link because, similar to how value differences contribute to confidence in one's own learning, SPE can be used to assess validity of the participant's model of the group and thus, confidence in others' choices. Ultimately, the brain could perform similar computations to estimate confidence in our own and others' choices.

The aforementioned studies provoke interesting ideas and raise new questions. How do reward outcomes and confidence in preceding trials determine weights of different information on choice? How does the brain estimate confidence for external sources of information such as others' choices? Why is ACC involved in valuation of social information, computation of confidence for ambiguous sensory stimuli, and estimation of volatility in the environment? As hinted above, a cross-species approach could provide important insights into these questions.

Acknowledgments

This work is supported by the National Institutes of Health (grant R01 DA047870 to A.S.).

[1]Department of Psychological and Brain Sciences, Dartmouth College, Hanover, NH 03755, USA

*Correspondence:
soltani@dartmouth.edu (A. Soltani).

https://doi.org/10.1016/j.tics.2020.09.011

References

1. Guggenmos, M. *et al.* (2016) Mesolimbic confidence signals guide perceptual learning in the absence of external feedback. *Elife* 5, e13388
2. Zhang, L. and Gläscher, J. (2020) A brain network supporting social influences in human decision-making. *Sci. Adv.* 6, eabb4159
3. Soltani, A. and Izquierdo, A. (2019) Adaptive learning under expected and unexpected uncertainty. *Nat. Rev. Neurosci.* 20, 635–644
4. Sarafyazd, M. and Jazayeri, M. (2019) Hierarchical reasoning by neural circuits in the frontal cortex. *Science* 364, eaav8911
5. Stolyarova, A. *et al.* (2019) Contributions of anterior cingulate cortex and basolateral amygdala to decision confidence and learning under uncertainty. *Nat. Commun.* 10, 1–14
6. Bang, D. and Fleming, S.M. (2018) Distinct encoding of decision confidence in human medial prefrontal cortex. *Proc. Natl. Acad. Sci. U. S. A.* 115, 6082–6087
7. Kolling, N. *et al.* (2016) Value, search, persistence and model updating in anterior cingulate cortex. *Nat. Neurosci.* 19, 1280–1285
8. Spitmaan, M.M. *et al.* (2020) Multiple timescales of neural dynamics and integration of task-relevant signals across cortex. *Proc. Natl. Acad. Sci. U. S. A.* 117, 22522–22531
9. Lak, A. *et al.* (2020) Dopaminergic and prefrontal basis of learning from sensory confidence and reward value. *Neuron* 105, 700–711
10. Lak, A. *et al.* (2020) Reinforcement biases subsequent perceptual decisions when confidence is low, a widespread behavioral phenomenon. *Elife* 9, e49834