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EDITORIAL

The Many Faces of Learning-Guided Cognitive Control

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Cognitive control refers to processes that enable adaptive, goal-directed behavior. Once ascribed to smart agents that willfully biased behavior in a top-down fashion (Norman & Shallice, 1986), an emerging "learning perspective" embodies the view that associative learning and memory processes are central to control (for recent reviews, see Abrahamse et al., 2016; Braem & Egner, 2018; Chiu & Egner, 2019; Egner, 2014). The guiding question of this special issue is how people learn to adapt control in a context-sensitive manner ("control learning"). Broadly speaking, the hypothesis probed by the articles herein is that this occurs via learning about regularities in the (task) environment, which in turn guides the engagement of control. This can take place in the form of incremental learning of the contextual likelihood of control demands (e.g., the accumulating realization that the current block of trials seems to be of high difficulty), and/or by associating specific stimuli or "events" with specific control demands, which can subsequently be retrieved in response to those stimuli/events. However, depending on context, adaptive control and the processes of learning and memory can also be at odds with one another. The studies in this special issue tackle three key themes surrounding learning-control interactions.

Theme 1: How People Adapt to Variations in the Likelihood of Control Demand

This core theme was addressed by several studies in this special issue, most of which employed a variant of the proportion congruent (PC) paradigm whereby the likelihood of control demand varies across blocks (lists) of trials. Spinelli and Lupker (2021) developed a new confound-minimized design by varying the proportion of neutral and incongruent trials in a Stroop task to reaffirm and strengthen the assumptions that individuals are learning about list-level conflict frequency and such learning supports (proactive) control. Suh and Bugg (2021) applied a new analytic approach to demonstrate incremental, trial-by-trial control learning in abbreviated lists of the Stroop task, thereby showing how control is dialed up or down as a function of accumulating low (congruent) or high (incongruent) demand trials.

Chen et al. (2021) observed a pattern that mimics the list-wide PC effect by using a reward manipulation. Selectively rewarding high demand trials led to a reduction in the Simon effect compared to rewarding low demand trials both for rewarded and nonrewarded items. An interesting question raised by these findings is whether statistical learning about the likelihood of control demand in general is sensitive to reinforcement or other motivational influences. Bejjani and Egner (2021) used incidental encoding of feedback events to probe how/whether reinforcement plays a role in control learning. The upshot was that people seem to engage in building a statistical prediction of trial types (e.g., expecting congruent trials in mostly congruent lists) and that confirmation of those predictions works as reinforcement, thus promoting control learning. However, neither a manipulation of feedback type (performance contingent vs. noncontingent feedback) nor analyses of individual differences in reward sensitivity provided strong support for the role of reinforcement or motivation in control learning. Similarly, in contrast to some forms of reward learning, Bejjani et al. (2021) found evidence indicating no benefits of a 24-hr consolidation period on control learning in a list-wide task-switching paradigm manipulating switch likelihood.

As is evident from these studies, control learning takes various forms, and shapes how people overcome conflict (Bejjani & Egner, 2021; Chen et al., 2021; Spinelli & Lupker, 2021; Suh & Bugg, 2021) and switch flexibly (Bejjani et al., 2021) based on the statistics of the environment. The study by Trach et al. (2021) suggests that learning about likely demands can occur at several levels (possibly independently), including one that sits above the level of single task sets, specifically learning about sequences of tasks.

Theme 2: How Learning of the Likelihood of Control Demand Differs From Using Explicit Cues to Adjust to Control Demand

While the studies described above relied on participants learning about control demand through experiencing the task, which typically occurs implicitly (Blais et al., 2012), people may also use explicit cues or instructions to adjust their control settings (which is presumably less reliant on learning). Studies in this special issue support two intriguing insights that have begun to emerge over recent years: (a) experiential (learning-guided) and cued adjustments seem to be dissociable modes of control, and (b) experiential, learning-guided

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control seems to be observed more easily/be more powerful than control engagement based on explicit cues about upcoming demand.

In the study by Suh and Bugg (2021), the authors probed for relative contributions of experiential control and explicit control (based on cues provided before each abbreviated list) to reduced congruency effects. They revealed dissociable yet interdependent effects: both experiential and (smaller) cue-guided control effects were observed, and experiential control was often relatively disengaged when explicit cuing was provided. Further supporting the notion that experiential and explicit control engagement are dissociable, Gonthier et al. (2021) showed that young children who struggle with using explicit cues for engaging control nevertheless display robust signatures of experiential control learning in list-wide and item-based PC protocols.

By contrast, Jiménez et al. (2020) built on other recent observations (Bugg et al., 2015; Bugg & Smallwood, 2016; Jiménez & Méndez, 2013) to buttress the counterintuitive finding that successful use of explicit cues for conflict control is surprisingly difficult to observe; over 10 experiments, they showed that people use explicit trial-by-trial cues under rather limited circumstances. While trial-by-trial explicit cues often do not result in smaller congruency effects, experience-based control is well known to produce such effects, in the shape of the so-called congruency-sequence effects, whereby an incongruent N-1 trial results in a smaller congruency effect on trial N, arguably due to an up-regulation of control. In line with other recent studies (e.g., Dignath et al., 2019; Grant et al., 2020; Spapé & Hommel, 2008), Yang et al. (2021) here showed that this effect, too, involves an associative learning component. Specifically, the degree to which this effect is expressed depends on the similarity of the control demands across trials.

Theme 3: When Control and Processes of Learning and Memory Are at Odds

In addition to learning processes guiding control, a wide range of situations can arise where control and learning or memory processes are at odds with each other. While some of these instances are part of the core canon of the control literature (e.g., the classic Stroop task requires control to counteract long-term memory stimulus–response associations), there are many other instances of such control-learning and control-memory interactions that are not yet mapped out. Two articles in this special issue investigated novel questions in this domain.

As an example of how cognitive control can be required to counteract maladaptive associations, Moretti et al. (2021) showed that executing a response in a cued task switching protocol leads to associative strengthening of the task set, even when the response was performed in error due to “task confusion.” This strengthening of the “incorrect” task set can negatively affect subsequent task performance unless it is counteracted by corrective control processes, and Moretti et al., showed that these processes are successfully recruited if given adequate time.

Dames and Pfeuffer (2021) also investigated performance errors, but here testing the question of whether control may disrupt memory processes. Based on Wessel’s (2018) adaptive posterror processing account, they reasoned that control processes that follow the commission of an error may temporarily obstruct working memory representations of the task rules. They found support for this idea using a novel design in which task responses were contingent across trials, thereby requiring participants to maintain in working memory the response they executed on the previous trial.

Future Directions Inspired by the Special Issue

The articles in this special issue expand our understanding of control learning and raise interesting questions for future research. One unresolved question that several articles in this special issue addressed regards the role of reinforcement and motivation. While reinforcement events like reward (Chen et al., 2021) may contribute to learning about control demand, neither feedback nor reward sensitivity was related to the magnitude of control learning (Bejjani & Egner, 2021). In contrast, the prospect of reward may affect the use of explicit cues (Suh & Bugg, 2021). This suggests that control engagement based on explicit cues may be more dependent on reward-sensitive decision-making processes (i.e., choosing to use or not use the cues [i.e., engaging or avoiding effort; Kool et al., 2010]) than learning-guided control, which could account for why the latter may well represent the most common and powerful mode of control engagement (thus supporting the *raison d’être* of our special issue!). Nonetheless, future research should also consider the drawbacks of learning-guided control, for instance, whether control may be misguided by previously learned control associations in a changing environment.

Another open question concerns the time-course and persistence of control learning. The results of Suh and Bugg (2021) suggest that at least some forms of control learning are observable within relatively few (10) trials, but generally it remains unclear both how much experience is needed to produce evidence for control learning and how long control learning persists. The study of Bejjani et al. (2021) may inspire additional studies that examine control learning following some delay. Whereas Bejjani et al., anticipated a benefit of a 24-hr delay based on theories of consolidation, conversely one might ask about the rate of decay for control learning, including how this rate is influenced by the amount of initial experience one has engaging learning-guided control. Such studies would provide a unique perspective on the interaction of control learning and memory.

Finally, future research should continue the path set by Gonthier et al. (2021) by examining the developmental trajectory of control learning, including trajectories of learning-guided and cue-based control in children and older adults (see also Bugg, 2014). Examining differences in control learning between other groups such as memory-impaired individuals may also inform the interplay between control learning and memory.

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