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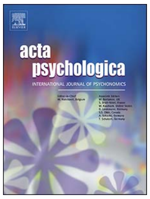

A role for proactive control in rapid instructed task learning

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ABSTRACT

Humans are often remarkably fast at learning novel tasks from instructions. Such rapid instructed task learning (RITL) likely depends upon the formation of new associations between long-term memory representations, which must then be actively maintained to enable successful task implementation. Consequently, we hypothesized that RITL relies more heavily on a proactive mode of cognitive control, in which goal-relevant information is actively maintained in preparation for anticipated high control demands. We tested this hypothesis using a recently developed cognitive paradigm consisting of 60 novel tasks involving RITL and 4 practiced tasks, with identical task rules and stimuli used across both task types. A robust behavioral cost was found in novel relative to practiced task performance, which was present even when the two were randomly inter-mixed, such that task-switching effects were equated. Novelty costs were most prominent under time-limited preparation conditions. In self-paced conditions, increased preparation time was found for novel trials, and was selectively associated with enhanced performance, suggesting greater proactive control for novel tasks. These results suggest a key role for proactive cognitive control in the ability to rapidly learn novel tasks from instructions.

1. Introduction

Imagine a group whose car is stuck in sand. To succeed in freeing their car they need to generate an effective collaborative effort. Some individuals would need to pull up the front of the car, one individual must quickly dig underneath the front wheel, and yet another would place a piece of wood underneath the wheel. None of them has done this before, and a critical feature is their ability to coordinate their effort in a timely and efficient manner. Each person's operation is quite simple, yet requires making novel decisions (such as when to place the piece of wood underneath the wheel). In this scenario, they may instruct one another what to do, but it would be critical to make sure to start the maneuver when all of them have understood the instructions and indicated that they are ready to carry out the instructions. Thus, a key question – the focus of the current study – is whether individuals utilize proactive cognitive processes to prepare to execute newly (relative to previously practiced) instructed tasks.

The ability to engage in rapid instructed task learning (RITL; “rittle”; Cole, 2009; Cole, Bagic, Kass, & Schneider, 2010) is not only an essential skill for human social groups, but also appears to be a uniquely human cognitive achievement (Cole, Laurent, & Stocco, 2013a; Meiran, Cole, & Braver, 2012). Although the processes, dynamics, and proficiency with which novel tasks are learned has long been a mainstay of cognitive psychology (Monsell, 1996; Newell & Simon, 1972; Rabbitt, 1997; Rosenbloom, 2012; Schneider & Shiffrin, 1977), there has been a recent rejuvenation of interest in RITL due to the introduction of new experimental methodologies that enable more sophisticated and detailed investigations of its component processes (Cole et al., 2013a; Liefooghe, Wenke, & De Houwer, 2012; Meiran et al., 2012; Ruge & Wolfensteller, 2010; Wenke, Gaschler, & Nattkemper, 2005).

A key feature and primary focus of the more recent investigations of RITL has been on examining the processes that are initiated immediately after novel task instructions are provided – on the very first trial. This is essential for isolating RITL from other processes that occur later in practice, given that long-term memory traces can facilitate performance on even just the second trial performing a task. The major recent innovation has involved obtaining a stable estimate of first encounter novel task behavior for each subject (Cohen-Kdoshay & Meiran, 2009; Cole, 2009; Hartstra, Kühn, Verguts, & Brass, 2011; Wenke et al., 2005). This involves the use of many novel tasks, such that behavioral and/or neural indices can be measured immediately after the instructions are processed with high statistical power. A second innovation has been to isolate the cognitive processes engaged during RITL, testing if they are distinct from cognitive processes engaged when the task is practiced, or if the same processes are involved but to different degrees (Cole et al., 2013a).

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As the car example above indicates, it is not only important that individuals be able to understand the instructions and be able to immediately carry them out. In some contexts, it is also critical to be able to indicate when one is ready to execute the instructions. The ability to prepare successfully for an upcoming task is a form of proactive cognitive control. According to the Dual Mechanisms of Control (DMC) framework (Braver, 2012; Braver, Gray, & Burgess, 2007), cognitive control can be flexibly utilized in two distinct operating modes that vary in terms of their temporal dynamics and utility in different cognitive situations. In particular, the proactive control mode is one that is prospective or future-oriented, and involves sustained, active maintenance of task goals. It is primarily engaged in an anticipatory fashion, when predictive cues in the environment signal up-coming high control demands, which can be most successfully met based on advanced preparation. Proactive control stands in stark contrast to the reactive control mode, which instead is a present-focused, just-in-time process, involving the transient re-activation or retrieval of task goals (e.g., from long-term) memory based on either the detection of conflict/interference, or via associative (i.e., spreading activation) mechanisms triggered by features of the current situation.

Elsewhere we have argued that RITL contexts likely make particular demands on the engagement of proactive control (Cole, Braver, & Meiran, 2017). The key insight is that, under RITL conditions, the instruction period provides both a clear indication of high upcoming control demands (given that the task is novel), while also signaling in advance the task goals or rules that will be relevant. Moreover, because the task is novel, there are only weak or nonexistent long-term memory representations of the relevant cognitive task procedure. Thus, when environmental features appear indicating that it is time to perform the novel task, these features are unlikely to enable successful retrieval or reactivation of task goals and rules through either episodic/associative pathways or conflict-based triggering. Consequently, in order to ensure successful RITL task performance, proactive control (implemented via sustained active maintenance of task goals from the instruction period) is likely necessary.

A key question is whether individuals have the expected ability to engage proactive cognitive control under RITL conditions, along with the ability to prepare as needed to successfully perform novel tasks. Previous studies have provided a mixed answer to this question. Two early studies by Dixon and colleagues reported positive suggestive evidence. Dixon (1981) focused on stimulus selection effects during performance of a newly instructed choice task. In this study, participants were given a novel pair of letters that were arbitrarily mapped to right/left responses. Importantly, participants had to indicate when they were ready to execute the novel task. Results indicated that preparation time (termed "initiation time") was a function of the number of possible letter pairs, even when holding constant the number of possible letters. Dixon interpreted this result as indicating individuals prepared longer when they needed to select a novel algorithm (the set of stimulus-response mapping rules relevant for the currently instructed pair) to decide among the letter pairs, rather than just activate a single mapping rule. Dixon and Just (1986) focused on response selection effects in a choice task. In their paradigm, participants were given a new task in which the stimuli "x" and "o" were linked to a novel combination of movements that were specified by several parameters, such as the direction and extent of the movement. The results of that study show that preparation time was mostly determined by the complexity of the movement specification. Along a similar line, Longman, Lavric, and Monsell (2016) have recently shown that self-paced preparation in task switching was advantageous relative to experimenter-paced preparation, again suggesting that participants have some access to their readiness state. These studies thus support the possibility of proactive processes engaged during novel task preparation.

In contrast, a more recent cued task-switching study conducted by Meiran, Hommel, Bibi, and Lev (2002) suggests that individuals may not be effective in strategically preparing for upcoming task demands. Specifically, it was found that shorter preparation times were paradoxically related to better task performance as compared with long preparation. Meiran et al. (2002) interpreted their findings in terms of a lack of meta-cognitive awareness regarding task-set preparation. However, they based this interpretation on several key assumptions, one of which was that task switching must involve loading goals into working memory. This specific assumption was challenged, however, in later studies. Specifically, switching and working memory appear to be related to two separate individual-differences dimensions (Miyake & Friedman, 2012). Furthermore, experimental work employing working-memory load manipulations show minimal if any involvement of working memory in task switching (Kessler & Meiran, 2009; Kiesel, Wendt, & Peters, 2005; van 't Wout, Lavric, & Monsell, 2013). Additionally, in the Meiran et al. (2002) study, participants switched between highly practiced tasks, such that the potential absence of proactive processes may be selective to non-RITL contexts.

In contrast to standard cued task switching (i.e., with practiced tasks), a key requirement of RITL performance appears to be the loading of instructed components into working memory for task-set formation (Cole et al., 2010). In standard cued task-switching experiments, because the tasks are known beforehand and are indicated by unique cues, the task set can be retrieved from long-term memory with relative ease, and at least in some conditions, even automatically (Braverman & Meiran, 2010). In RITL paradigms, in contrast, participants likely need to form the task set in working memory based on instructions. Following from this observation, we hypothesized that individuals likely require additional proactive control processes (that take time and are prone to error) prior to performance of RITL tasks, because RITL tasks involve the formation of a task set in working memory (similar to the Dixon studies), rather than merely being retrieved from long-term memory (as in standard cue task-switching studies, such as Meiran et al., 2002).

To explicitly test the prediction that the need for proactive control increases in RITL situations, we took advantage of a recently developed paradigm for exploring RITL performance within a task-switching context (Cole, Ito, & Braver, 2016; Cole et al., 2010). This permuted rule operations (PRO) paradigm involves performance of tasks constructed from a set of 4 sensory semantic, 4 logical decision, and 4 motor response rules, generating 4 × 4 × 4 = 64 permuted rule sets (Fig. 1). Our core manipulation involved task-rule novelty such that 4 of the 64 possible tasks were extensively practiced before testing, while the remaining 60 tasks were novel combinations of familiar elements. Critically, all 12 rules were included in both the practiced and novel tasks, isolating task-practice effects by controlling for practice across individual rules. Note that the task-practice manipulation included practice both prior to and during (due to multiple practiced-task encounters) the "test" session. Thus, practiced tasks were (unlike novel tasks) encountered multiple times both recently and in a previous session.

As described above, a key prediction was that novel and practiced tasks would be distinguished in terms of how readiness times are related to actual task execution. First, we predicted that preparation for novel tasks would take longer than for familiar tasks, creating "novelty costs". While novelty costs are not particularly surprising, they provide an important validation of one of our key assumptions: that working-memory involvement is greater in novel than in practiced tasks. To test whether participants prepare for novel tasks in a strategic (proactive) manner, we additionally focused on the relationship between preparation time and task execution success. Specifically, our second prediction was that under conditions involving limited preparation time, the novelty cost would be reflected in poorer task performance when switching to novel tasks. In contrast, when preparation time is unrestricted (i.e., self-paced), we hypothesized that the novelty cost would be substantially reduced and/or even eliminated. The third prediction was that under self-paced conditions longer preparation times would be directly related to improved task performance (reduced