



# The effect of practice on $n-2$ repetition costs in set switching<sup>☆</sup>

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## ARTICLE INFO

### Article history:

Received 21 August 2014

Received in revised form 30 October 2014

Accepted 8 November 2014

Available online 26 November 2014

### PsycINFO classification:

2340

2346

### Keywords:

Task switching

Inhibition

ACT-R

Computational model

## ABSTRACT

Inhibition in set switching is inferred from so-called  $n-2$  repetition costs: slower response times to ABA sequences compared to CBA sequences (where A, B, and C are arbitrary labels for different tasks). These costs are thought to reflect the persisting inhibition of task A when it was disengaged recently (as is the case in an ABA sequence). In this study we were interested in whether more inhibition may be required when the tasks are relatively novel. To this end, we examined the effect of practice on the  $n-2$  repetition cost in nine participants across five experimental sessions, with 1222 trials performed in each session. The results show a clear reduction in the  $n-2$  repetition cost, being altogether absent from the final sessions. Such a reduction is predicted by both: (a) a recent computational model of the  $n-2$  repetition cost (Grange, Juvina, & Houghton, 2013) due to the gradual strengthening of task-related memory elements with practice to the point where inhibition has less impact; and (b) prior work showing smaller  $n-2$  repetition costs with greater cue–target association strength (Houghton, Pritchard, & Grange, 2009). In this paper, we integrate these two theoretical derivations by extending our computational model, which fit the current data—at the mean level, block level, and individual-subject (i.e., individual differences) level—well.

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## 1. Introduction

The human environment is increasingly busy, with many possible tasks competing for our attention at any given time. Sat at a computer, for example, there are a plethora of tasks that could be selected (e.g. writing, Internet-browsing, playing online chess). How are humans able to select the goal-relevant task (e.g. writing a manuscript) in the face of so many competitors? Once selected, how is the task maintained in the focus of attention, so that competing tasks do not interfere with ongoing performance? How is it that, when no longer goal-relevant, tasks can be switched quickly and efficiently?

The so-called task switching paradigm (Grange & Houghton, 2014; Kiesel et al., 2010; Vandierendonck, Liefoghe & Verbruggen, 2010) has provided much insight into the cognitive processes thought to enable successful maintenance and flexible shifting of task-sets (the mental representation of the task to perform; Logan & Gordon, 2001). In this paradigm, participants typically must rapidly switch between simple cognitive tasks on bivalent stimuli (e.g. odd/even and magnitude judgments on number stimuli). One component process thought to aid task switching is the inhibition of competing task-sets (Koch, Gade,

Schuch & Philipp, 2010; Mayr & Keele, 2000). When a task is required, the task-set must become active in working memory in order to be acted upon. However, such activation is hindered by the still-active representation from the previous trial; thus activation of the *current* task-set is thought to be coupled with the inhibition of the *previous* task-set (Mayr & Keele, 2000).

Evidence for inhibition in task switching comes from the backward inhibition paradigm (Mayr & Keele, 2000) where the participants switch between three potential tasks. It has been consistently shown that response times and errors are increased returning to a task after one intermediate task (e.g. ABA) compared to returning to a task not-so-recently performed (e.g. CBA). This  $n-2$  repetition cost is thought to reflect the persisting inhibition of task A, which hampers its re-activation when required soon after its inhibition (as in an ABA sequence). Inhibition in task switching has been shown to act on many different levels of the task-set, targeting those aspects of the trial-structure that generate the greatest inter-trial conflict (Houghton, Pritchard & Grange, 2009): the  $n-2$  repetition cost is modulated by altering cue/preparation-related processes (Gade & Koch, 2014; Grange & Houghton, 2009; Grange & Houghton, 2010b; Grange & Houghton, 2011; Houghton, Pritchard & Grange, 2009; Scheil & Kleinsorge, 2014), stimulus-related processes (Sdoia & Ferlazzo, 2008) and response-related processes (Philipp, Jolicoeur, Falkenstein & Koch, 2007; Schuch & Koch, 2003).

Although much is known about the  $n-2$  repetition cost, there are still some fundamental questions to be addressed. One such question we focus on in the current paper is whether more inhibition is required

<sup>☆</sup> We are grateful to Iring Koch and an anonymous reviewer for their helpful & thoughtful comments on an earlier draft. Part of this work was presented at the Experimental Psychology Society conference at Kent University, UK (April, 2014).

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when the tasks being performed are relatively novel; that is, we were interested in whether there was any modulation of the  $n-2$  repetition cost with extended practice. Recent studies have examined the effect of practice on standard task switching measures. For example, [Stoet and Snyder \(2007\)](#) and [Berryhill and Hughes \(2009\)](#) investigated the effect of practice on switch costs (the RT cost to task switches compared to task repetitions): [Berryhill and Hughes \(2009\)](#) found that the cost was reduced, but not eliminated; [Stoet and Snyder \(2007\)](#) found a reduction of the cost in two naive participants, but a slight increase for two non-naive participants. [Strobach, Liepelt, Schubert and Kiesel \(2012\)](#) also found that the switch cost reduced, but was not eliminated after practice; however, these authors observed that the mixing cost—the slower RT to a task repetition trial in a switching block compared to a task repetition trial when only that task is possible (i.e. a pure block)—was fully eliminated after practice. These results seem to converge on the finding that the switch cost cannot be eliminated even after extensive practice, suggesting that it reflects a core limitation to cognitive flexibility. However, none of these studies investigated the  $n-2$  repetition cost.

Indeed, upon considering prior work in this area, we derived—on the basis of two theoretical reasons—a clear prediction of a reduction of the  $n-2$  repetition cost with extended practice. One aspect of theory that predicts a reduction of the cost with practice regards the practice-driven reduction of conflict in working memory when switching, due to automatization of establishing the relevant attentional set (i.e., cue–target translation; see [Houghton, Pritchard & Grange, 2009](#)); the other arises from a recent computational model of inhibition in set switching ([Grange, Juvina & Houghton, 2013](#)) whereby increased practice of a task raises the resting activation levels of task-related memory elements, which over-rides short-term inhibition. We discuss each in turn below.

### 1.1. Automatisation of cue–target translation processes

One reason to predict a reduction of the  $n-2$  repetition cost with practice stems from the work of [Houghton and colleagues \(Grange & Houghton, 2010b; Houghton, Pritchard & Grange, 2009\)](#) who suggested that inhibition in a set switching context can be triggered by cue-related conflict in working memory (WM) when establishing the relevant attentional set. In their target-detection set-switching paradigm (similar to that of [Mayr & Keele, 2000](#), the participants were presented with four potential target ovals, with each differing on a unique visual property (e.g. one was angled, one was shaded, and one had a thick border; one was neutral and upright and served as a distractor). The participants were presented with a cue which signalled which target to search for on that trial (for example, a “square” cue might mean search for the shaded oval). [Houghton, Pritchard and Grange \(2009\)](#) argued that the participants must use the cue to activate a representation (i.e. attentional set) of which target to search for, a process they called cue–target translation. When the relevant target switches, the representation formed on the previous trial generates conflict in WM with the representation required on the current trial, triggering inhibition of the prior representation.

Supporting evidence comes from manipulating the *transparency* of the cue–target relationship; that is, the degree to which the cue exogenously provides the representation required to find the relevant target ([Grange & Houghton, 2010a](#)). For example, a cue–target relationship with low transparency would have no pre-experimental association with its paired target (e.g. a square cue being paired with a shaded oval target) whereas a highly-transparent cue–target relationship the cue would share some of the properties of the to-be-located target (e.g. a shaded rectangular cue being paired with a shaded oval target). Decreasing cue–target transparency increases the effort required to form an active representation of the target, increasing the amount of potential conflict in WM when a switch is required. For maximally-transparent cue–target pairings, very little (if any) cue–target translation is required, and thus little conflict arises in WM during a switch, triggering no/less inhibition. Across several studies,

[Houghton and colleagues](#) have shown that the magnitude of the  $n-2$  repetition cost is inversely related to the transparency of the cue–target relationship, being altogether absent when highly-transparent cue–target pairings are used ([Grange & Houghton, 2009](#); [Grange & Houghton, 2010b](#); [Grange & Houghton, 2011](#); [Grange, Juvina & Houghton, 2013](#); [Houghton, Pritchard & Grange, 2009](#)).

Such an account would predict a reduction of  $n-2$  repetition cost with extended practice due to the gradual automatization of cue–target translation processes. Using non-transparent cue–target pairings, cue–target translation is initially slow and effortful, requiring considerable work in WM to activate a target representation (what [Logan \(1988\)](#), might call an “algorithmic” process); thus, when a switch occurs, there is more in WM that can generate conflict (and hence inhibition). With practice, however, this slow process can be replaced by a fast automatic retrieval process, whereby prior instances of the cue–target relationship can be directly retrieved from long-term memory with little effort. Thus, when automated, cue–target translation requires less effort, and generates less conflict in WM when switching. With practice, non-transparent cue–target pairings might therefore behave like highly transparent cue–target pairings, because the cue can directly retrieve the target pairing. This is a natural prediction from our prior work, investigating how cue–target transparency modulates inhibition in set switching.

### 1.2. Predictions from a computational model of inhibition

In a previous paper ([Grange, Juvina & Houghton, 2013](#)), we presented a computational model to account for  $n-2$  repetition costs and benefits in set switching. This model was implemented in the ACT-R cognitive architecture ([Anderson, 2007](#)) and integrates other previous related work ([Juvina & Taatgen, 2009](#); [Lebiere & Best, 2009](#)). This model was able to account for  $n-2$  repetition costs by using the standard cognitive mechanisms embedded in ACT-R (e.g., memory activation due to frequency and recency of use) and a newly added inhibition mechanism ([Lebiere & Best, 2009](#)).<sup>1</sup> In the ACT-R model of the target-detection paradigm of [Houghton, Pritchard and Grange \(2009\)](#), correct performance on an individual trial required successive retrieval of “chunks” of information from declarative memory. For example, when presented with a square cue, the model needs to retrieve a chunk from declarative memory that represents the target that is paired with that cue. In ACT-R, a retrieval request returns the most active chunk; thus, the system must ensure that the correct chunk is the most active. The speed of retrieving a chunk is inversely related to its activation: highly active chunks are retrieved quickly and accurately.

In ACT-R, the total activation of a chunk is governed by the current context (e.g. through spreading activation from presented cues) as well as its base-level learning activation (BLL), which reflects the degree of practice with a particular chunk. It assumes that once a chunk is activated, its activation will begin to decay as a

<sup>1</sup> The model was not designed to account for standard task switching effects, such as the switch cost and its reduction with increased preparation. Indeed, in a standard task switching experiment (i.e. comparing task switch versus task repetition sequences) the model of [Grange et al. \(2013\)](#) would actually predict repetition costs (rather than the benefits observed) because in the model the most recently performed task is inhibited. (Although, it should be noted that the model can easily account for both  $n-1$  repetition benefits and  $n-2$  repetition costs if we assume a fast short-term store independent of long-term memory.) However, in backward inhibition paradigms, no task repetitions occur; it has been shown by [Philipp and Koch \(2006\)](#) that the  $n-2$  repetition cost is reduced/eliminated when immediate task repetitions are possible. It might be that when no task repetitions occur (i.e., there is no benefit of repetition priming) the cognitive systems utilise a strategy of automatically inhibiting just-performed tasks (although the mechanism by which this strategy is adopted is not modelled by [Grange et al.](#)). It should also be noted that models that do account for standard task switching effects (e.g., [Altmann & Gray, 2008](#); [Schneider & Logan, 2005](#)) cannot account for  $n-2$  repetition costs. Thus, although the model is far from complete, it does account for empirical effects that extant models do not.

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