

Short article

Inhibition of irrelevant category–response mappings

Darryl W. Schneider

Vanderbilt University, Nashville, TN, USA

Frederick Verbruggen

Vanderbilt University, Nashville, TN, USA, and Ghent University, Ghent, Belgium

When switching tasks, performance tends to be worse for $n - 2$ repetitions than with $n - 2$ switches. This $n - 2$ repetition cost has been hypothesized to reflect task-set inhibition: specifically, inhibition of irrelevant category–response mappings involved in response selection. This hypothesis leads to divergent predictions for situations in which all tasks involve the same stimulus categories: An $n - 2$ repetition cost is predicted when response sets differ across tasks, but not when the response set stays the same. The authors tested these predictions by having subjects perform relative judgements with different reference points. In Experiment 1, the stimulus categories were the same across reference points, but the response set either differed or stayed the same (the multiple- and single-mapping conditions, respectively). An $n - 2$ repetition cost was found in the multiple-mapping condition but not in the single-mapping condition. Experiment 2 provided evidence against the possibility that these divergent effects reflected differences in memory load. These findings confirm predictions that link $n - 2$ repetition costs to inhibition of irrelevant category–response mappings.

Keywords: Task switching; Inhibition; Response selection; Reference points.

The ability to reconfigure the cognitive system to adapt to changing task demands is considered to be an integral aspect of cognitive control. The postulated means by which this reconfiguration can be accomplished are diverse, but one idea is that it involves *task-set inhibition*—inhibiting irrelevant task sets (configurations of the cognitive system) to facilitate implementation of a relevant task set

(Arbuthnott & Frank, 2000; Mayr & Keele, 2000; for a review, see Mayr, 2007). However, task sets are multifaceted, and the task sets for different tasks (or variants of the same task) probably overlap to some degree, making it unnecessary—and perhaps even detrimental—to inhibit entire task sets. For this reason, we argue that only specific components of a task set are inhibited

Correspondence should be addressed to Darryl W. Schneider, Department of Psychology, Carnegie Mellon University, Pittsburgh, PA 15213, USA. E-mail: dws@cmu.edu

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and that identifying those components is important for understanding the nature of task-set inhibition. The purpose of the present study was to investigate the hypothesis that task-set inhibition reflects inhibition of irrelevant category–response mappings (i.e., associations linking stimulus categories to responses) involved in response selection, as suggested by recent work (Gade & Koch, 2007; Philipp & Koch, 2005; Schuch & Koch, 2003; see also Arbuthnott, 2005; Mayr, 2002).

TASK-SET INHIBITION

When switching between three tasks (denoted A, B, and C), performance tends to be worse for $n - 2$ repetitions (e.g., the third trial of ABA sequences) than with $n - 2$ switches (e.g., the third trial of CBA sequences). Mayr and Keele (2000) argued that this $n - 2$ repetition cost can be explained by task-set inhibition: When performing an ABA sequence, switching from Task A to Task B involves inhibition of the task set for Task A. When switching back from Task B to Task A, extra time is required to overcome this inhibition, resulting in a performance cost for $n - 2$ repetitions. When performing a CBA sequence, inhibition of the task set for Task A has occurred less recently, so there is less inhibition to overcome, resulting in relatively faster performance for $n - 2$ switches. However, task sets are ill-defined in many situations (Schneider & Logan, 2007), making it unclear which task-set components are actually inhibited.

Inhibition in response selection

Recent work by Koch and colleagues (Gade & Koch, 2007; Schuch & Koch, 2003; see also Koch, Gade, & Philipp, 2004; Mayr, 2002) suggests that task-set components associated with response selection are inhibited when switching tasks. In their Experiments 2–4, Schuch and Koch explored $n - 2$ repetition effects in the context of a go/no-go paradigm in which subjects responded on go trials and did not

respond (or pressed both response keys simultaneously) on no-go trials. They compared ABA and CBA sequences for which Task B was either a go trial or a no-go trial and found that $n - 2$ repetition costs were present after go trials but absent after no-go trials. Schuch and Koch interpreted their results as evidence that task-set inhibition was associated with response selection because no-go trials only differed from go trials in that no response had to be selected. Furthermore, given that stimulus categories associated with different tasks are typically assigned to the same response keys in task-switching experiments (making the responses multi-valent), Schuch and Koch hypothesized that irrelevant category–response mappings are inhibited when switching tasks to reduce interference in response selection.

Gade and Koch (2007) provided additional evidence for inhibition of category–response mappings by manipulating response-set overlap across tasks. In their experiments, subjects switched among four tasks. Three of the tasks had complete stimulus-set overlap (the tasks were associated with separate dimensions of the same stimulus) and complete response-set overlap (all tasks required “left” or “right” vocal responses); these were referred to as trivalent (T) tasks. The stimulus set for the fourth task—referred to as a univalent (U) task—did not overlap with that of the trivalent tasks, and there was either no response-set overlap (e.g., by requiring “up” or “down” vocal responses) or complete response-set overlap (by requiring “left” or “right” vocal responses) with the trivalent tasks. Gade and Koch found that $n - 2$ repetition costs were always present for TTT sequences but only occurred for TUT sequences with complete response-set overlap. They interpreted these findings as evidence that overlapping response sets can induce task-set inhibition.

Stimulus categories across tasks

In the work of Koch and colleagues, as well as in most task-set inhibition studies, different tasks are associated with different stimulus categories.

For example, the tasks (and their corresponding categories) may be colour (red or blue), shape (circle or triangle), and size (small or large) judgements (e.g., Schneider, 2007). Irrelevant category-response mappings exist whenever different categories are assigned either to the same response or to different responses. However, the hypothesis that task-set inhibition reflects inhibition of irrelevant category-response mappings involved in response selection does not necessarily require different stimulus categories across tasks. This point was illustrated in a study by Philipp and Koch (2005). In their experiments, subjects performed a single task (e.g., a magnitude judgement with stimulus categories of smaller and larger), but were cued to respond in a specific modality on each trial (vocal, finger, or foot response). Philipp and Koch contrasted $n - 2$ modality repetitions (e.g., finger, vocal, finger) with $n - 2$ modality switches (e.g., foot, vocal, finger) and found $n - 2$ repetition costs, as might be expected because there were irrelevant category-response mappings involved in response selection—the same categories were associated with different responses across trials.

But what would happen if the same categories were associated with the same responses across trials? If all tasks involved the same category-response mappings, then all mappings would remain relevant across trials. With no irrelevant category-response mappings to inhibit, no $n - 2$ repetition cost would be expected. Thus, for situations in which all tasks involve the same categories, the hypothesis that task-set inhibition reflects inhibition of irrelevant category-response mappings leads to divergent predictions: An $n - 2$ repetition cost is predicted when response sets differ across tasks, but not when the response set stays the same.

The first prediction was confirmed by Philipp and Koch (2005), but we sought to replicate their finding without changing response modalities. If the critical determinant of inhibition is the presence of irrelevant category-response mappings (arising from assigning the same categories to different response sets, as in Philipp & Koch, 2005), then an $n - 2$ repetition cost should still

be observed when response sets differ within the same modality (e.g., different sets of response keys). The second prediction has yet to be tested because most task-set inhibition experiments do not allow for situations in which ABA and CBA sequences can be formed from tasks involving the same stimulus categories and the same response sets—such conditions are generally associated with a series of task repetitions (e.g., AAA). However, in the present study, we used a procedure that allowed us to test both predictions: reference-point switching (Schneider & Logan, 2007).

THE PRESENT STUDY

In the experiments reported below, subjects judged whether a single-digit number was smaller or larger than a reference point. The relevant reference point was 2, 5, or 8 and switched every trial, permitting $n - 2$ repetitions (e.g., 252) and $n - 2$ switches (e.g., 852), as in typical studies of task-set inhibition. Schneider and Logan (2007; see also Verbruggen, Schneider, & Logan, in press) demonstrated that reference-point switching not only yields $n - 1$ switch costs, but also modulation of task-specific effects associated with the reference point (see also Dehaene, 1989), indicating that reference-point switching can produce standard task-switching effects. More importantly, these effects could be linked to reconfiguration of a specific task-set component used in response selection: the reference point.

In the present study, we allowed for reconfiguration of an additional task-set component: the response set. Given that the stimulus categories (smaller and larger) are the same across reference points, response sets can be manipulated such that irrelevant category-response mappings do or do not exist during response selection. Response sets were manipulated between subjects in two conditions. In the *multiple-mapping* condition, each stimulus category was assigned to multiple response keys, with a unique key used for each reference point. Thus, there were

irrelevant category–response mappings across reference points during response selection, leading to the prediction of an $n - 2$ repetition cost. Observing such a cost would represent a within-modality replication of Philipp and Koch's (2005) cross-modality finding. In the *single-mapping* condition, each stimulus category was assigned to a single response key used for all reference points. Thus, all category–response mappings remained relevant across reference points during response selection, leading to the novel prediction of no $n - 2$ repetition cost. Note that these predictions are based on the assumption that category–response mappings—not reference points—are inhibited; otherwise, one would expect $n - 2$ repetition costs in both conditions.

In Experiment 1, we compared performance in the single- and multiple-mapping conditions to test our predictions of divergent $n - 2$ repetition effects. The absence of a cost in the single-mapping condition, coupled with the presence of a cost in the multiple-mapping condition, would represent converging evidence that task-set inhibition reflects inhibition of irrelevant category–response mappings used in response selection. In Experiment 2, we introduced and manipulated a concurrent memory load in the single-mapping condition to determine whether the results of Experiment 1 reflected differences in memory load between the mapping conditions.

EXPERIMENT 1

Method

Subjects

A total of 40 students from Vanderbilt University completed the experiment for partial course credit. A total of 20 students were assigned to each mapping condition.

Apparatus

The experiment was conducted using E-Prime software (Psychology Software Tools, Pittsburgh, PA) running on computers that displayed stimuli

on monitors and registered responses from QWERTY keyboards.

Task, stimuli, and category–response mappings

The task was to categorize a stimulus as smaller or larger than a reference point. The numbers 2, 5, and 8 were reference points, and the numbers 1, 3, 4, 6, 7, and 9 were stimuli. Each number measured 4×6 mm and was displayed in white 12-point Courier New font on a black background and viewed at a distance of about 60 cm.

Category–response mappings were manipulated between subjects. In the single-mapping condition, each stimulus category was assigned to a single response key used for all reference points. The smaller category was assigned to the Z key (pressed with the left index finger), and the larger category was assigned to the / key (pressed with the right index finger). Note that while category–response mappings stay the same across reference points, stimulus–response mappings do not (e.g., the stimulus 4 warrants a Z response with reference points 5 and 8, but a / response with reference point 2). Thus, the congruency that exists across category–response mappings does not extend to the stimulus–response mappings for most of the stimuli.

In the multiple-mapping condition, each category was assigned to multiple response keys, with a unique key used for each reference point. For half of the subjects in this condition, the smaller category was assigned to the S, D, and F keys for the reference points 2, 5, and 8, respectively, and the larger category was assigned to the J, K, and L keys for the reference points 8, 5, and 2, respectively. For the other half of the subjects, the assignments for the reference points 2 and 8 were reversed: The smaller category was assigned to the F and S keys for the reference points 2 and 8, respectively, and the larger category was assigned to the J and L keys for the reference points 2 and 8, respectively. The S, D, and F keys were pressed with the left ring, middle, and index fingers, respectively, and the J, K, and L keys were pressed with the right index, middle, and ring fingers, respectively, such that the keys associated with the same reference point were pressed with

corresponding fingers. For the multiple-mapping condition, reminders of the category-response mappings were displayed in the bottom corners of the screen for the duration of the experiment.

Procedure

Subjects were seated at computers in private testing rooms after providing informed consent. Instructions were presented onscreen and were explained by the experimenter.

The experiment was divided into blocks of 74 trials, with the first two trials involving different randomly selected reference points and stimuli. For the remaining 72 trials, reference points and stimuli were randomly selected subject to the following constraints. First, each reference point was presented 24 times, with no immediate repetitions across trials. Second, $n - 2$ repetitions and $n - 2$ switches each occurred 36 times, with no more than four consecutive occurrences of the same type of transition. Third, each stimulus was presented 12 times, with no immediate repetitions across trials. Fourth, each of the 18 possible stimulus-reference-point combinations occurred a minimum of 3 times. For every subject, each block was generated independently.

Each trial began with the presentation of a reference point in the centre of the screen. After 250 ms, a stimulus was presented 14 mm below the reference point. The reference point and the stimulus remained onscreen until a response key was pressed; then the stimuli were erased, and the next trial commenced after 500 ms.

The experiment began with one practice block, followed by seven experimental blocks (for a total of 518 experimental trials). The experiment lasted about 20 min.

Results and discussion

The practice block, the first two trials of each experimental block, and trials with response

times (RTs) exceeding 3 standard deviations of each subject's mean RT (2.44% of trials) were excluded from analysis (other trimming procedures yielded similar results). Only correct trials that were preceded by at least two correct trials were included in the RT analysis. Mean RT and error rate (ER) were calculated for each type of transition in each mapping condition. These data are provided in Table 1 and were submitted to separate 2 (mapping: multiple or single) \times 2 (transition: $n - 2$ repetition or $n - 2$ switch) mixed measures analyses of variance (ANOVAs).

In the RT analysis, there was a significant main effect of mapping, $F(1, 38) = 54.92$, $MSE = 43,864.10$, $p < .001$, $\eta_p^2 = .59$. RT was longer in the multiple-mapping condition (932 ms) than in the single-mapping condition (585 ms), a difference that is discussed below. The main effect of transition was not significant, $F(1, 38) = 1.70$, $MSE = 496.90$, $p = .20$, but there was a significant interaction between mapping and transition, $F(1, 38) = 14.84$, $MSE = 496.90$, $p < .001$, $\eta_p^2 = .28$. The interaction reflects different $n - 2$ repetition effects (calculated by subtracting $n - 2$ switches from $n - 2$ repetitions) across mapping conditions (see Table 1). Planned comparisons indicated that in the multiple-mapping condition, there was a significant $n - 2$ repetition *cost* of 26 ms, $F(1, 19) = 7.73$, $MSE = 854.48$, $p < .05$, $\eta_p^2 = .29$, whereas in the single-mapping condition, there was a significant $n - 2$ repetition *benefit* of 12 ms, $F(1, 19) = 11.58$, $MSE = 139.32$, $p < .005$, $\eta_p^2 = .38$.¹

Mean ER was 3.90%, and there was no evidence of a speed-accuracy trade-off. In the ER analysis, neither main effect was significant (both $ps > .14$), and there was only a trend toward an interaction, $F(1, 38) = 2.98$, $MSE = 1.40$, $p = .09$, $\eta_p^2 = .07$. Planned comparisons indicated that in the multiple-mapping condition, there was a significant $n - 2$ repetition *cost* of 0.86%, $F(1, 19) = 6.81$, $MSE = 1.07$, $p < .05$,

¹ A significant $n - 2$ repetition benefit of 17 ms, $F(1, 19) = 8.88$, $MSE = 331.23$, $p < .01$, $\eta_p^2 = .32$, was present in the single-mapping condition even when trial sequences involving the stimuli 1 and 9 (for which stimulus-response mappings stay the same across reference points) were excluded, indicating that the benefit is not due to retrieval of stimulus-response mappings that bypasses the category level.

Table 1. Mean response time and error rate as a function of transition and mapping condition in Experiment 1

Transition	Multiple mapping		Single mapping	
	RT	ER	RT	ER
<i>n</i> - 2 Repetition	945 (42)	4.47 (0.64)	579 (22)	3.73 (0.45)
<i>n</i> - 2 Switch	919 (40)	3.61 (0.70)	591 (24)	3.79 (0.50)
Difference	26	0.86	- 12	- 0.06

Note: RT = response time (in ms); ER = error rate (percentage of incorrect responses); standard errors in parentheses.

$\eta_p^2 = .26$, whereas in the single-mapping condition, there was a nonsignificant *n* - 2 repetition benefit of 0.06%, $F < 1$, a pattern consistent with the RT data (see Table 1).

The divergent *n* - 2 repetition effects across mapping conditions support the predictions we derived from the hypothesis that task-set inhibition reflects inhibition of irrelevant category-response mappings involved in response selection. In the multiple-mapping condition, in which there were irrelevant category-response mappings across reference points, an *n* - 2 repetition cost was observed. In the single-mapping condition, in which all category-response mappings remained relevant across reference points, an *n* - 2 repetition benefit was observed. We discuss this benefit in the General Discussion.

While there was no difference in ER across mapping conditions, RT was much longer in the multiple-mapping condition than in the single-mapping condition (see Table 1). Given this substantial difference, one might argue that our divergent *n* - 2 repetition effects somehow reflect a relation between RT and inhibition. For example, longer RTs may reflect greater task difficulty, and this may lead to increased inhibitory processing as a means of reducing difficulty by suppressing task-irrelevant information. As a result, *n* - 2 repetition costs may be more likely at longer RTs.

We can use our data to evaluate this argument in two ways. First, correlational analyses of our data are inconsistent with the idea that *n* - 2 repetition effects change from benefits to costs as RT becomes longer. In the single-mapping condition, the *n* - 2 repetition benefit was larger (i.e., the

difference between *n* - 2 repetitions and *n* - 2 switches was more negative) for subjects with longer RTs ($r = -.54$, $p < .05$). In the multiple-mapping condition, there was no relationship ($r = .18$, $p = .44$). Second, distributional analyses of our data are inconsistent with the idea that *n* - 2 repetition effects reverse with RT. For each subject in each mapping condition, we constructed the cumulative probability distribution function (CDF) of RT for each transition, using quantiles of 0.1, 0.3, 0.5, 0.7, and 0.9. The quantiles were averaged across subjects for each combination of transition and mapping condition to produce group CDFs (Ratcliff, 1979), which are plotted in Figure 1. At every quantile in the single-mapping condition, there was an *n* - 2 repetition benefit (significant at four of the five quantiles, $p < .05$). At every quantile in the multiple-mapping condition, there was an *n* - 2 repetition

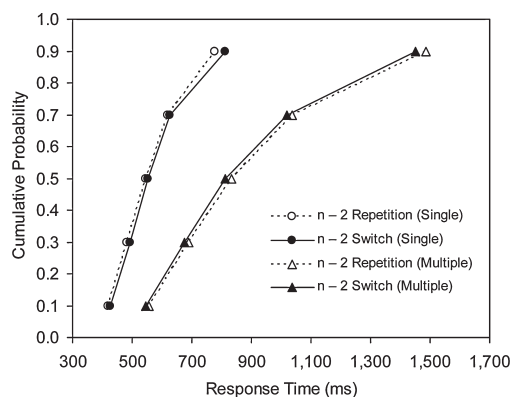


Figure 1. Cumulative probability distribution functions of response time for each combination of transition and mapping condition in Experiment 1.

cost (significant at three of the five quantiles, $p < .05$). Critically, these divergent effects were present even for overlapping regions of the distributions (in the range of 550–800 ms; see Figure 1), providing strong evidence against a relation between RT and inhibition.

An alternative possibility is that there is no direct relation between RT and inhibition, but both are affected by a variable that differs across mapping conditions. One such variable is memory load. In the single-mapping condition, subjects had to maintain only two category–response mappings in memory, whereas in the multiple-mapping condition, subjects had to maintain six category–response mappings in memory.² It is possible that the higher memory load in the multiple-mapping condition had the dual effects of prolonging RT and increasing inhibition of task-irrelevant information in memory, with the latter yielding an $n - 2$ repetition cost.

We investigated the possible effects of memory load in Experiment 2. Given that the multiple-mapping condition may already have a high memory load associated with it, we introduced and manipulated a concurrent memory load in the single-mapping condition only. In Experiment 2, the relative judgement task was embedded within a memory task. Prior to a short block of relative judgements, subjects were presented with a study list of either two or six letters (low and high loads, respectively). The study list had to be maintained in memory while subjects performed the relative judgements, after which time they indicated whether a probe letter had been present or absent in the study list.

The question of interest is whether $n - 2$ repetition effects vary with memory load. If differences in memory load were responsible for the divergent $n - 2$ repetition effects observed in Experiment 1, then there should be an $n - 2$ repetition benefit under low load that is either reduced or reversed (i.e., becomes a cost) under high load. By contrast, if memory load was not

responsible for the divergent effects, then there should be an $n - 2$ repetition benefit that is unaffected by load.

EXPERIMENT 2

Method

Subjects

A total of 20 students from Vanderbilt University, none of whom had participated in Experiment 1, completed the experiment for partial course credit.

Apparatus

The apparatus was the same as that in Experiment 1.

Tasks, stimuli, and category–response mappings

The relative judgement task and its associated stimuli were the same as those in Experiment 1 except that only the category–response mappings for the single-mapping condition were used. Reminders of the mappings were displayed in the bottom corners of the screen during task performance.

The memory task was to determine whether a probe letter had been present or absent in a previously studied list of letters. The letters C, F, H, J, L, M, N, R, X, and Y constituted the stimulus set from which the study lists were constructed. Each letter measured 4×6 mm and was displayed in white 12-point Courier New font. Each study list was constructed by randomly permuting the 10 letters in the stimulus set and then selecting the first two (low load) or six (high load) letters. Probes were present or absent in the study lists equally often in each load condition. If the probe was present, one of the two (low load) or six (high load) letters in the study list was randomly selected as the probe with equal probability across list positions. If the probe was absent, one of the eight (low load) or four (high load) letters in the complement set to the study list was

² However, we note that there was no explicit requirement to maintain the category–response mappings in memory in the multiple-mapping condition, as reminders of the mappings were displayed in the bottom corners of the screen for the duration of the experiment.

randomly selected as the probe with equal probability. Each study list was generated independently in each load condition and for each subject with the constraint that consecutive study lists could not be identical.

Category–response mappings for the memory task were the same for all subjects. The present category was assigned to the Z key (pressed with the left index finger), and the absent category was assigned to the / key (pressed with the right index finger). Reminders of the mappings were displayed in the bottom corners of the screen during the memory probe.

Procedure

Subjects were seated at computers in private testing rooms after providing informed consent. Instructions were presented onscreen and were explained by the experimenter.

The experiment was divided into runs consisting of three phases. In the first phase, a list of letters was studied. The word *STUDY* was displayed in the centre of the screen for 1,500 ms and was followed by a blank screen for 500 ms. Study letters were then presented one at a time in the centre of the screen. Each letter was displayed for 750 ms and was followed by a blank screen for 500 ms, with this cycle repeating until all letters in the study list had been presented. The words *GET READY* were then displayed in the centre of the screen for 1,500 ms, signalling the transition from the study list to the relative judgement task.

In the second phase, a short block of 14 relative judgement trials was performed. For each block, the first two trials involved different randomly selected reference points and stimuli. For the remaining 12 trials, reference points and stimuli were randomly selected subject to the following constraints. First, each reference point was presented at least three times, with no immediate repetitions across trials. Second, $n - 2$ repetitions and $n - 2$ switches each occurred six times, with no more than four consecutive occurrences of the same type of transition. Third, each stimulus was presented two times, with no immediate repetitions across trials. For every subject, each block was generated independently. The trial

procedure and timing parameters were identical to those of Experiment 1.

In the third phase, memory for the study list was probed. A blank screen appeared for 500 ms after the last relative judgement trial, after which time the word *TEST* was displayed in the centre of the screen, and a probe letter was presented 22 mm below it. Reminders of the category–response mappings for the memory task also appeared at this time. This display remained onscreen until a response key was pressed; then the screen was cleared, and the first phase of the next run commenced after 500 ms.

Load conditions were manipulated within subjects in separate halves of the experiment. Half the subjects had the low-load condition followed by the high-load condition, and the other half had the reverse order. Subjects were informed of their load condition order at the start of the experiment, and they received an onscreen prompt when the load changed from low to high (or vice versa). Each half of the experiment involved 14 runs, with the first 3 runs treated as practice, leaving 11 probes and 154 experimental trials per load condition. The experiment lasted about 20 min.

Results and discussion

The practice runs, the first two trials of each experimental block, and trials with RTs exceeding 3 standard deviations of each subject's mean RT in each load condition (2.10% of trials) were excluded from analysis. For the memory task, only correct trials were included in the RT analysis. For the relative judgement task, only correct trials that were preceded by at least two correct trials were included in the RT analysis, as in Experiment 1.

Memory task

Mean RT and ER were calculated for probe performance in each load condition and were submitted to separate one-way repeated measures ANOVAs. The effect of load was significant for both RT, $F(1, 19) = 14.66$, $MSE = 171,225.03$, $p < .005$, $\eta_p^2 = .44$, and ER, $F(1, 19) = 7.69$, $MSE = 52.74$, $p < .05$, $\eta_p^2 = .29$. Probe RT was longer with high

load (1,948 ms) than with low load (1,447 ms), and ER was higher with high load (8.19%) than with low load (1.82%). These results indicate that the load manipulation was effective.

Relative judgement task

Mean RT and ER were calculated for each type of transition in each load condition. These data are provided in Table 2 and were submitted to separate 2 (load: low or high) \times 2 (transition: $n - 2$ repetition or $n - 2$ switch) repeated measures ANOVAs.

In the RT analysis, there was a significant main effect of transition, $F(1, 19) = 5.57$, $MSE = 745.66$, $p < .05$, $\eta_p^2 = .23$. RT was shorter for $n - 2$ repetitions (574 ms) than with $n - 2$ switches (588 ms), replicating the $n - 2$ repetition benefit observed in the single-mapping condition in Experiment 1. The main effect of load was not significant, $F(1, 19) = 2.93$, $MSE = 6,080.99$, $p = .10$, though RT was numerically longer with high load (596 ms) than with low load (566 ms). Most importantly, the interaction between load and transition was not significant, $F(1, 19) = 1.12$, $MSE = 495.11$, $p = .30$. Contrary to the idea that a high memory load may induce an $n - 2$ repetition cost, the data exhibited a trend in the opposite direction (see Table 2), with a numerical increase in the $n - 2$ repetition benefit from low load (9 ms) to high load (20 ms).

Mean ER was 2.88%, and there was no evidence of a speed-accuracy trade-off. In the ER analysis, none of the effects were significant (all $ps > .16$), but the numerical trend was for an $n - 2$ repetition benefit in each load condition, a pattern consistent with the RT data

(see Table 2) and the data of the single-mapping condition in Experiment 1.

The results of Experiment 2 provide evidence against the possibility that the divergent $n - 2$ repetition effects in Experiment 1 were produced by differences in memory load. Replicating the single-mapping condition of Experiment 1, we observed an $n - 2$ repetition benefit in both load conditions. This finding is consistent with our hypothesis that task-set inhibition reflects inhibition of irrelevant category-response mappings involved in response selection. In the single-mapping condition, regardless of memory load, there are no irrelevant category-response mappings to inhibit, leading to the prediction of no $n - 2$ repetition cost. The results of Experiment 2 support this prediction.

An issue that warrants discussion is why there was no effect of load on reference-point switching at all. One possibility is that the load manipulation was ineffective, but the probe data suggest otherwise. RT was longer and ER was higher with high load than with low load, indicating that a high load taxed memory more than did a low load. Similar results using comparable memory tasks have been obtained by others and have been interpreted as evidence of an effective load manipulation (e.g., Lavie, Hirst, de Fockert, & Viding, 2004). Another possibility is that an irrelevant concurrent memory load simply does not affect reference-point switching. This idea is consistent with recent findings of no memory load effects on task switching (Liefoghe, Barrouillet, Vandierendonck, & Camos, 2008; Logan, 2007; see also Logan, 2004). For example, Liefoghe and colleagues found that $n - 1$ switch costs and

Table 2. Mean response time and error rate as a function of transition and load in Experiment 2

Transition	Low load		High load	
	RT	ER	RT	ER
$n - 2$ Repetition	561 (25)	2.91 (0.84)	586 (33)	2.32 (0.58)
$n - 2$ Switch	570 (23)	2.94 (0.57)	606 (37)	3.35 (0.83)
Difference	-9	-0.03	-20	-1.03

Note: RT = response time (in ms); ER = error rate (percentage of incorrect responses); standard errors in parentheses.

overall RTs were unaffected by a concurrent memory load that varied from three up to six or more items. Our results are consistent with these findings and reinforce our argument that reference-point switching is comparable to standard task-switching situations.

If a concurrent memory load does not prolong RT in reference-point switching, then what produced the substantial difference in RT between the mapping conditions in Experiment 1? We argue that it is the number of alternative category–response mappings involved in response selection. A well-established phenomenon in choice tasks is that RT becomes longer as the number of response alternatives increases (Hick, 1952; Hyman, 1953). Our data represent another instance of this robust effect and support our contention that the critical difference between mapping conditions is at the level of category–response mappings.

GENERAL DISCUSSION

By investigating task-set inhibition in the context of reference-point switching, we were able to test divergent predictions of $n - 2$ repetition effects for situations in which the stimulus categories stayed the same across trials. In Experiment 1, we contrasted $n - 2$ repetition effects in multiple- and single-mapping conditions. In the multiple-mapping condition, an $n - 2$ repetition cost was predicted and observed, providing a within-modality replication of Philipp and Koch's (2005) cross-modality finding. In the single-mapping condition, an $n - 2$ repetition cost was not predicted and not observed. In fact, we obtained an $n - 2$ repetition benefit in that condition. This benefit was replicated in Experiment 2, wherein we found that it was unaffected by a concurrent memory load. In the remainder of this article, we discuss inhibition of irrelevant

category–response mappings in response selection in greater detail and the relative contributions of costs and benefits to $n - 2$ repetition effects.

Inhibiting irrelevant category–response mappings

While interpreting their results, Schuch and Koch (2003, p. 101) noted that “it remains an open question as to whether only the category–response rules become inhibited or whether the relevant set of categories is also inhibited” (see also Philipp & Koch, 2005). In the present study, the relevant set of categories (smaller and larger) was relevant for all reference points in both mapping conditions; therefore, inhibition of categories (as well as stimulus–category mappings) was unlikely and cannot account for the divergent $n - 2$ repetition effects that we observed. Thus, our results indicate that inhibition of irrelevant category–response mappings alone is sufficient to produce an $n - 2$ repetition cost.

Why inhibit category–response mappings at all? Following Schuch and Koch (2003; see also Arbutnott, 2005; Hübner, Dreisbach, Haider, & Kluge, 2003; Mayr, 2002), we argue that inhibition reduces interference from irrelevant category–response mappings across trials (even if those mappings are not associated with stimulus-set or response-set overlap), thereby facilitating response selection. We assume that response selection (broadly defined) may involve establishing two mappings, one from the stimulus to a category and one from the category to a response (see Pashler & Baylis, 1991).³ In principle, the stimulus–category mapping can be done the same way in both mapping conditions by using the reference point to determine what is small and what is large and categorizing the stimulus accordingly.⁴ However, the category–response mapping differs across mapping conditions. In the single-mapping condition, the category–response

³ Although we refer to semantic categories, it is possible that the mapping involves spatial categories (e.g., left and right) that are associated with semantic categories (e.g., smaller and larger).

⁴ Additional RT analyses of our data revealed patterns of distance effects (shorter RTs with increasing distance between reference point and stimulus) that are more consistent with performance of relative judgements (Dehaene, 1989; Schneider & Logan, 2007)

mapping involves a single alternative that does not vary across reference points, whereas in the multiple-mapping condition, a choice must be made among multiple alternatives based on the relevant reference point. Biasing the choice process toward the relevant category-response mapping by inhibiting irrelevant category-response mappings would facilitate accurate responding, and it is in this way that task-set inhibition can be construed as an adaptive cognitive control process.

On costs and benefits

Task-set inhibition studies tend to be focused on detecting $n - 2$ repetition costs; less attention has been paid to identifying situations in which such costs may be absent or even reversed (but see Arbuthnott, 2005; Gade & Koch, 2007; Mayr, 2002; Schuch & Koch, 2003). While the presence of a cost in the multiple-mapping condition in Experiment 1 is important, we argue that the presence of a benefit in the single-mapping condition in Experiments 1 and 2 is just as informative with respect to evaluating hypotheses of task-set inhibition.

Why was there an $n - 2$ repetition benefit in the single-mapping condition? We suggest that when switching reference points, the previous reference point retains residual activation that persists across trials (for a similar idea, see Allport, Styles, & Hsieh, 1994). When that reference point becomes relevant again, reinstatement of the reference point may be primed by such residual activation, which is likely to be stronger the more recently the reference point has been used. Thus, reference-point switching could occur more quickly for $n - 2$ repetitions than for $n - 2$ switches. In the absence of inhibition, this positive priming of reference points would

produce an $n - 2$ repetition benefit, as we observed in the single-mapping condition. An alternative (though not mutually exclusive) explanation of the benefit is that reference-point cues rather than—or in addition to—reference points were primed (e.g., see Mayr & Kliegl, 2003, Exp. 3).⁵ Given that each reference point was associated with a single cue, every $n - 2$ reference-point repetition was also a cue repetition. Priming would lead to faster cue encoding (e.g., see Schneider & Logan, 2005) and earlier reinstatement of the associated reference point, yielding a benefit in performance.

It is important to be cautious when labelling an effect as a cost or a benefit (Jonides & Mack, 1984), in part because it is possible that a cost might mask a benefit. We think that such an effect may have occurred in the multiple-mapping condition. In that condition, the benefit accrued from priming of reference points (or cues) may have been masked by a larger cost associated with inhibition of irrelevant category-response mappings involved in response selection, such that the net effect would be an $n - 2$ repetition cost, as we observed. Thus, following Schneider (2007), we suggest that $n - 2$ repetition effects in some task-set inhibition studies may reflect a mix of inhibition and activation, with costs sometimes masking benefits (or vice versa).⁶ We think that further research devoted to teasing apart the relative contributions of inhibition and activation to $n - 2$ repetition effects and determining the conditions under which costs or benefits will be obtained is vital for understanding task-set inhibition.

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than with distance-independent categorization of stimuli that might arise from alternative labelling of stimulus categories across reference points.

⁵ We thank Gordon Logan for suggesting this explanation.

⁶ The reverse situation—a benefit masking a cost—was suggested by Mayr and Kliegl (2003, Exp. 3) as an explanation of their finding of an $n - 2$ repetition benefit when task cues repeated from trial $n - 2$ to trial n . On the basis of correlational analyses of their data, they argued that task-set inhibition still occurred, but that the cost of inhibition was masked by a benefit from positive priming of cues. We thank Ulrich Mayr for drawing our attention to this interpretation.

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