Task cues lead to item-level backward inhibition with univalent stimuli and responses

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Running head: Backward inhibition & univalent mappings

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Abstract

Backward inhibition may aid our ability to switch between tasks by counteracting the tendency to repeat a recently performed task. Current theory asserts that conflict between tasks during performance plays a key role in inducing the effect. However, a study by Costa and Friedrich (2012) suggests that backward inhibition might occur without this type of conflict being present. To better understand the mechanisms underlying backward inhibition, we investigated the roles of between-task conflict, task-based instructions, and task cues. Experiment 1 tentatively supported the view that conflict between tasks is not necessary for backward inhibition to be present, and suggested that either the use of task-based instructions or the provision of specific task-cues might be sufficient to generate the effect. Experiment 2 ruled out task-based instruction as a likely cause of backward inhibition in this context. Experiment 3 showed that the provision of task-cues was sufficient to drive a significant backward inhibition effect, but only when stimuli and responses (as well as tasks) repeated. Overall, these results indicate that between-task conflict during performance is not necessary for backward inhibition to be applied, and that task cues have a key role in generating the effect.

Keywords: inhibition, task switching, cue processing, conflict

Introduction

Daily life involves switching back and forth between different rules that determine what actions are currently appropriate, in response to changing internal and external demands. Actions that may be appropriate at one moment (e.g. pressing down on the accelerator pedal of a car when driving) may become inappropriate at the next (e.g. if a pedestrian steps in front of the car). It has been proposed that a cognitive control mechanism that might help us to perform such task-switches is that of "backward inhibition" (Mayr & Keele, 2000), whereby the task being switched away from becomes inhibited in order to prevent it from competing so strongly with the new task that it is performed again by mistake. As well as facilitating a task-switch, this inhibition is thought to persist such that it also has the effect of impairing a subsequent switch back to the initial task (It is therefore measured using the $n - 2$ repetition cost, which is calculated by comparing performance when switching back to the initial task to performance when switching to a third task). It is easy to see that such a mechanism could improve switching in contexts where the task being switched away from could easily be performed again by mistake, such as in the example of driving. It would seem to be less useful in a situation where it was always impossible to perform the wrong task by mistake because the stimuli and responses for each task were completely separate – e.g. when switching from accelerating in a car to eating a sandwich. Backward inhibition being found in such a situation (Costa & Friedrich, 2012) is therefore intriguing, and potentially also important in terms of our understanding of when, and why, we employ cognitive control mechanisms. For instance, it might indicate that backward inhibition is applied proactively across all situations perceived as requiring task-switching, as opposed to being recruited reactively, in response to a high level of conflict between tasks during task-performance. This is in line with the dual mechanism of control framework, proposed by Braver and collegues (Braver, 2012; Braver, Gray, & Burgess, 2007) which states that

cognitive control functions via two distinct modes. One of these modes is reactive, where cognitive control is recruited after interference has been detected; but a second mode is proactive control, which occurs in advance of an interference-eliciting stimulus. In the current paper, we investigate whether conflict between tasks in the form of sharing of stimuli and responses between tasks is indeed unnecessary for the backward inhibition effect to be present, and investigate alternative sources of the effect.

The current understanding of backward inhibition leans towards backward inhibition being a reactive measure rather than a proactive measure. Koch, Gade, Schuch, and Philipp (2010) reviewed the backward inhibition literature and concluded (in line with Mayr & Keele, 2000) that backward inhibition appears to be a reactive mechanism, being applied when conflict between tasks is detected in order to deal with that conflict. In particular, they highlighted the likely roles of two sources of conflict, both of which would be triggered during performance of a task: first, the sharing of stimuli between tasks (since each stimulus might require a different response in different tasks) (see Sdoia & Ferlazzo, 2008); second, the sharing of responses between tasks (since each response has a different meaning in different tasks) (see Gade & Koch, 2007). Thus, they suggest that conflict arising during performance of a task is necessary for backward inhibition to be triggered. Furthermore, they speculate that backward inhibition is deployed by a similar conflict-monitoring mechanism to the one postulated in the study of single task response conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Cognitive control mechanisms related to response conflict are thought to be part of the reactive mode of the dual mechanism of control framework (Botvinick, Cohen, & Carter, 2004; Braver, 2012). Therefore, Koch et al.'s (2010) association of backward inhibition with the response conflict-monitoring mechanism strongly suggests that they consider backward inhibition to be a reactive measure.

Furthermore, Sexton and Cooper's computational model of task switching, which currently is the only model that includes both *n* – 1 switch costs (the decrease in performance on a switch trial as compared to a repeat trial) and *n* – 2 repetition costs (the decrease in performance on the final trial in a ABA trial sequences as compared to a CBA trial sequences), is based on the assumption that backward inhibition is deployed in response to conflict during task processing. Within this model, conflict units monitor for when there is a large degree of co-activation, driven by shared stimuli and responses, between two tasks. When a set level of co-activation is detected the conflict units bias processing between competing task representations, through inhibition of conflicting task representations.

However, not all studies support the notion that backward inhibition is a reactive measure. Costa and Friedrich (2012, Expt. 1) eliminated sources of conflict during task processing (i.e., shared stimuli and shared responses) and still found an *n* – 2 repetition cost. That is to say, within Costa and Friedrich's (2012) experiment there was arguably nothing for the cognitive control mechanism to react to, in terms of sources of conflict between tasks, and yet still backward inhibition appears to have been applied. For each of the three tasks the stimuli and responses were "univalent" (they only applied to a single task). Nevertheless, a statistically significant *n* – 2 repetition cost of 16ms was present in that study. Costa and Friedrich's result is potentially important with respect to the mechanism whereby backward inhibition is triggered as their finding would seem to indicate that the backward inhibition effect cannot only be a reactive measure of cognitive control, solely generated when conflict between tasks is experienced during task-performance, but that there must also be other triggering conditions. Costa and Friedrich suggested that their result supported a view that backward inhibition could be generated proactively at the time of processing a task cue to prepare the appropriate task, rather than reactively in response to interference experienced while processing a stimulus and selecting an appropriate response.

Given that the previous understanding of backward inhibition is that it is a reactive mechanism we aimed first to test whether evidence of backward inhibition could indeed be found when there was no presumably no reason for a reactive measure (i.e., no sharing of stimuli or responses between tasks). If we found evidence of backward inhibition within Experiment 1 then it could not be due to the need to control between-task conflict arising from the sharing of either stimuli or responses between tasks. Hence, we would need to look for an alternative source of the effect.

One alternative to backward inhibition being a reactive mechanism is that perhaps the triggering of backward inhibition does not require conflict to be present at all. Instead, perhaps backward inhibition can be a proactive mechanism in that it is the act of switching between what are seen as alternative task rules that causes backward inhibition to be applied. The key issue here is that with univalent stimuli, every target stimulus *unambiguously* specifies which response is needed on that trial, so there is actually no need to use the concept of a "task" or "rule" at all, and any task-cues presented are unnecessary. But maybe when we nevertheless tell participants that they will perform and switch between specific tasks, and we cue them on each trial as to which task is relevant (as is usually done in task-switching experiments), we make them *expect to need* to use some form of cognitive control in order to help them to switch between tasks. For instance, possibly task-cues allow the early selection of goal relevant information, and this causes backward inhibition to be applied (cf. Braver, 2012). In other words, participants might apply backward inhibition not because they need to, but because the experimental conditions have induced them to do so.

This idea has some similarity with the experiments of Dreisbach, Goschke, and Haider (2007, see also Dreisbach, 2012), who looked at the switch cost (rather than the $n - 2$ repetition cost). In those studies the group of participants who were told that stimulus-response mappings conformed to two distinct tasks showed significant costs of switching

between these tasks while another group who were instructed only about the mappings themselves showed no costs. To investigate whether a similar situation might apply to the backward inhibition effect, we used two groups in Experiment 1. The "task-instruction" group were instructed that they would be performing different tasks, and that they must successfully switch between them; further, informative task-cues indicated which task should be performed on each trial. The other group, termed the "mapping-instruction" group, were simply told to perform according to the six stimulus-response mappings, and they were not shown informative trial-by-trial task-cues. There were no systematic differences, however, in terms of the target stimuli and responses between the two groups. If backward inhibition can be generated proactively without sharing of stimuli and responses but only when participants are aiming to switch between what are presented as alternative tasks, then we should see $n - 2$ repetition cost in the task-instruction group but not in the mapping-instruction group.

Before describing the first experiment, we wish briefly to discuss which types of trial-sequences might be the most appropriate for measuring a backward inhibition effect. There are two aspects to this issue. The first aspect is to do with whether task-level backward inhibition (due to returning to a recently abandoned task, e.g. *colour*, but not to any particular stimulus or response) can be distinguished from item-level backward inhibition (due to repeating the specific stimulus and/or response, e.g. *red* / *right index,* when returning to a recently abandoned task). Item-level inhibition would contribute to the $n - 2$ repetition cost if the same item (stimulus or response; note, these are perfectly correlated in the Costa & Friedrich, 2012, design and therefore also in our design) was present on trials $n - 2$ and n; task-level inhibition should be present regardless of repetition of individual features. Mayr and Keele (2000) argued that in their studies backward inhibition appeared to occur largely at the task-level. However, they did not specifically test for the significance of the effect on ABA trial sequences where no item-level repetition was present, instead basing their

conclusion on the lack of a statistically significant difference between repetition and no-repetition sequences. (The same is also true of Costa and Friedrich, 2012.) As part of our analysis we specifically tested for significance of the effect on ABA trial sequences where no item-level repetition was present as well as separately testing for significance of the effect on ABA trial sequences where item-level repetition was present.

The second issue regarding which sequences to analyse has to do with whether it is possible or not to isolate a "pure" measure of backward inhibition in our data, independent from any potential confounding effect of "episodic mismatch" (Gade, Souza, Druey, & Oberauer, 2017; Grange, Kowalczyk, & O'Loughlin, 2017). The episodic mismatch idea is based upon the suggestion that any event (such as an experimental trial) will cause an episodic memory trace of that event to be stored that includes a number of relevant features (e.g., cue, stimulus, response) (Logan, 1988, 1990; Neill, 1997). When that task is used again, the stored memory trace from the last time it was used is retrieved. Importantly, if the features of the retrieved event differ from the event that is currently being processed (e.g. if a different target stimulus is presented) then a mismatch occurs and this causes a performance cost, whereas the identical repetition of a trial would facilitate performance. Importantly, this episodic mismatch effect would affect ABA sequences more than CBA sequences, and hence could be misinterpreted as indicating the presence of backward inhibition. Our item-level analysis will allow us to test for backward inhibition unconfounded by episodic mismatch.

Experiment 1

In this experiment, our main aim was to test whether conflict between tasks (caused by sharing of stimuli and responses) is necessary for backward inhibition to be applied. To achieve this, we aimed to replicate Experiment 1 of Costa and Friedrich (2012) whilst further reducing the likelihood of stimuli and responses triggering associations with irrelevant tasks.

We tested two groups of participants. The "task-instructions" group (analogous to the participants in Costa & Friedrich's study) received the usual instructions to switch between tasks, as well as being shown trial-by-trial task-cues before each target. In contrast, no mention of tasks was made to the "response-mappings" group. We predicted that we would see one of three possible patterns of results. Firstly, we might see no evidence of backward inhibition in either group. This would differ from the findings of Costa and Friedrich, but would support the idea of backward inhibition as a mechanism that reacts to conflict between tasks experienced during task-performance. Secondly, we might see evidence of backward inhibition in the task-instructions group only. This would suggest that there is something about the task-switching set-up (i.e., the task-based instructions and/or trial-by-trial task-cues) that proactively causes the effect. Thirdly, it is conceivable that we might see evidence of backward inhibition in both groups. This would suggest that the effect is driven in a rather automatic fashion, perhaps dependent upon the visual stimulus dimensions used (colour, shape, line).

Methods

Participants

Eighty participants were tested[1] in total for either course credit or £5 compensation for their time. As with all the experiments participants were randomly assigned to groups. The criteria

[1] Our intention in all of these experiments was to include at least 36 participants data analysed per group. Thirty-six participants would give us around an 80% probability of detecting an effect size (d_z) of 0.45 or above for a two-tailed paired t-test (i.e., when comparing ABA and CBA trial sequences) and an effect size (d) of 0.67 or above for a two-tailed independent samples t-test, using an alpha of .05. An exception to this rule was in Expt. 3 where a factor of cue type order was included for counterbalancing purposes only, with an N of 18 in each group.

for participant exclusions were set *a priori:* participants' overall accuracy rate had to be above 70% (Arbuthnott & Woodward, 2002) and each participant had to have fewer than 10% of experimental trials removed due to response time being below 200ms or above 2000ms (Costa & Friedrich, 2012; Los, 1999). Additional exclusions were made to ensure matching numbers of participants within each specific feature-button mapping subgroup (see below) between task-instruction and mapping-instruction groups, with an exclusion for accuracy leading to an exclusion of the least accurate matched participant in the other group, and exclusion for there being too many trials outside the allowed response times leading to exclusion of the matched participant with the highest number of excluded trials in the opposing group. In Experiment 1 one participant was excluded for accuracy and three participants were excluded for response times, with a further four participants excluded to maintain matching.

Following exclusions, in the task-instruction group there were 36 participants aged between 17 and 28 (mean age 20.6, 30 females) and in the mapping-instruction group there were 36 participants aged between 18 and 35 (mean age 20.4, 29 females). All participants in this article gave their informed consent.

The study (and all others in this article) was approved by the ethics board at the School of Psychology, University of Aberdeen.

Materials: Stimuli and Tasks

The tasks and stimuli used were based on Costa and Friedrich's (2012) Experiment 1. In the task-instruction group there were three tasks, each with two target stimuli: red/green for the colour tasks; triangle/circle for the shape task, and horizontal/vertical lines for the line orientation task. Slight changes to the stimuli from Costa and Friedrich's design were made to remove potential associations with other tasks that could induce unwanted task-conflict. Hence, colours were presented here within a non-iconic blob shape (rather than a square) to

avoid activating the shape task, and lines were presented without any surrounding shape. The task for the upcoming trial was cued with the relevant cue word – COLOUR, LINE or SHAPE – for either 500 or 1000ms, cue duration being determined at random on each trial. Each target stimulus was mapped to its own response button (six in total). The actual mapping of stimuli to buttons was counterbalanced so that there were six different variations (subgroups), as follows. Red, vertical and triangle were always on buttons 1 to 3; and green, horizontal and circle were always on buttons 4 to 6. Left-to-right ordering of tasks was the same on both hands: i.e., if red was button 1, then green would be button 4; if red was button 2, green would be button 5, etc.; see Fig. 1. Unlike Costa and Friedrich's study where participants responded using only one finger, the current study instructed participants to use a different finger for each button (index, middle and ring fingers on both hands); again, this was to reduce the sharing of relevant features between tasks in order to further reduce the likelihood of task-conflict.

The same target stimuli and response buttons were used in the mapping-instruction group as in the task-instruction group. However, so that there was no connotation with the idea of separate "tasks", in this group a meaningless string of letters was shown in place of the verbal task cue: DDDDDD, BBBBB, or JJJJ. These strings were selected at random on each trial and therefore could not inform the participant of the upcoming task. Stimulus presentation was random on each trial, so task and stimulus repeats between consecutive trials as well as from trial $n - 2$ to trial n were possible. Approximately 50% of ABA trial sequences involved repetition of both the target stimulus and the response from trial $n - 2$; there could be no repetition of either target stimulus or response from trial $n - 2$ to n on CBA trial sequences.

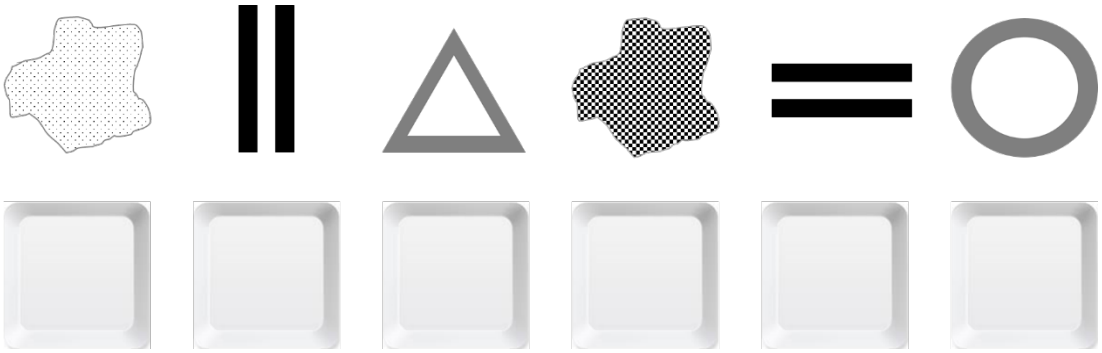

Figure 1. The stimuli and response mappings for Experiment 3: each stimulus was mapped to an individual button-box key, keys arranged left-to-right (red mapped to left-most key, etc.). Changes were made to Costa and Friedrich's (2012) stimuli to make them more distinct from each other. Spotty and the checked patterns for the "blob" shapes represent the colours red and green respectively. The other stimuli were coloured as shown.

Procedure

Participants sat at a comfortable distance from a computer screen running E-Prime 2.0 software (Psychology Software Tools, Inc., http://www.pstnet.com) with a Cedrus-response box (Cedrus Corporation, 2003) in front of them to make responses on. The instructions were presented on the computer screen. Participants in the task-instruction group were instructed that they would be switching between three different tasks, whereas care was taken with the mapping-instruction group to never mention the words "task", "line", "colour" or "shape", in order to avoid causing participants into thinking in terms of separate tasks. Participants in the task-instruction group started with four practice blocks which consisted of practising each task individually (for 20 trials each) and then practising the three tasks together for 40 trials. Participants in the mapping-instruction group were instructed to memorize the response-mappings of six stimuli and then they had three mixed practice blocks of 20 trials each and then a 40 trial mixed practice block, so that the total amount of practice was the same for both groups. To help them learn the response-mappings during practice, participants in both

groups were given feedback for 500ms via the word 'INCORRECT' shown in magenta if they gave an incorrect response.

After practice, participants progressed to the experimental blocks, of which there were 10 consisting of 50 trials each. A trial started with 500ms blank screen. The cue was then presented for either 500ms or 1000ms creating two cue-target intervals. After the cue, the target was presented and it stayed on the screen until a response was made (see Fig. 2). At the end of each block participants were shown on-screen their average reaction time and their total accuracy during the block to encourage fast and accurate responses.

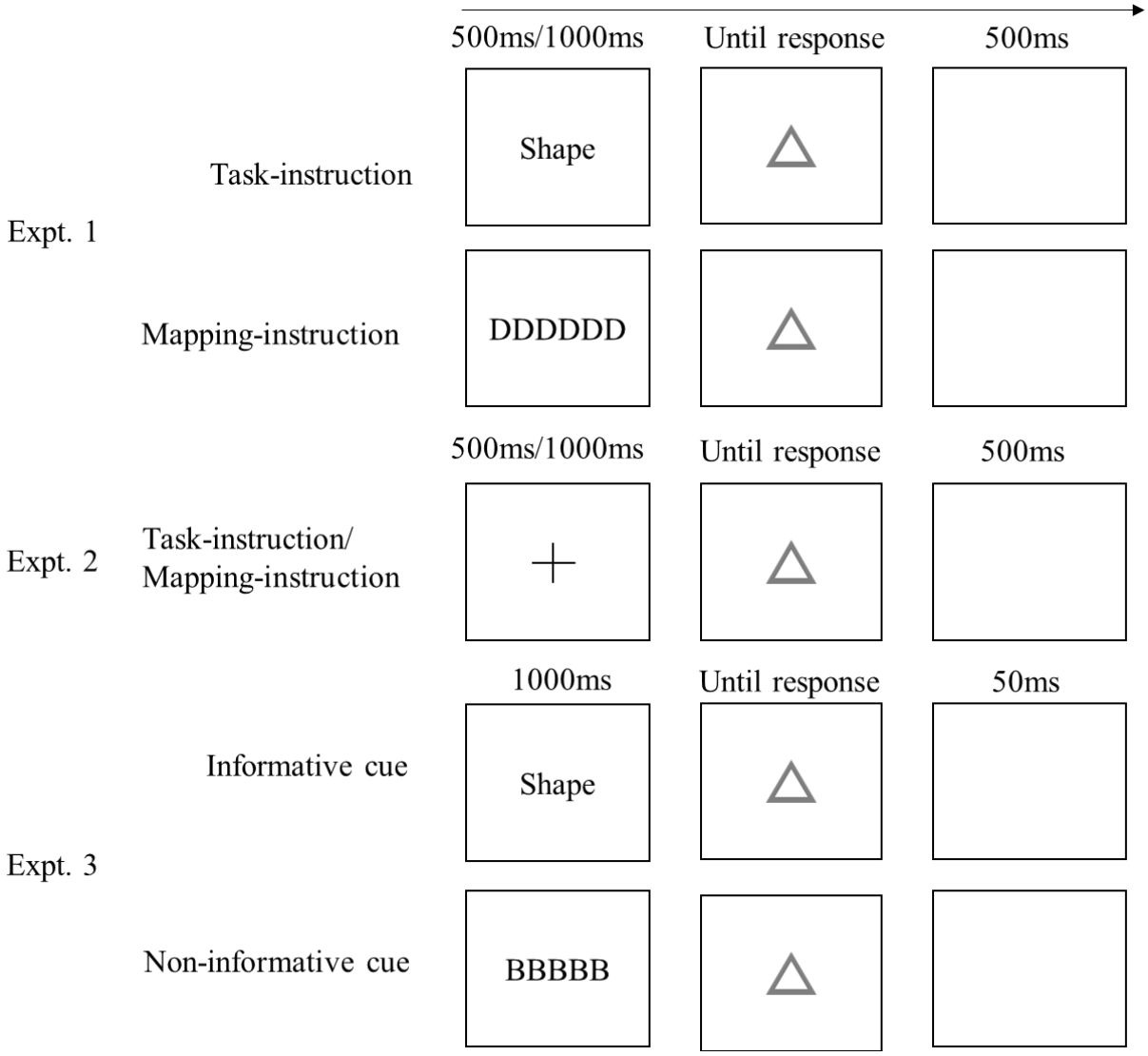

Figure 2. Experiment 1, 2 and 3 trial procedure.

Design & Analysis[2]

The mean reaction time (RT) for each participant and mean percentage of trials on which an error was made (percentage error; PE) were analysed. Each trial was retrospectively coded according to the two prior trials, and only ABA and CBA trial sequences were included in the data analysis (on average 44% of trials sequences were the trial sequences of interest [range 38% - 53%]). The first two trials of every block were excluded, as were trials that had RTs below 200ms or above 2000ms and if the response of either of the previous two trials (n – 2 and n – 1) was inaccurate then that trial (n) was excluded. Additionally, for the RT analysis the current trial also had to have an accurate response. For the main analysis (i.e., not split by item-transition) on average 15% of trials of interest were excluded (per participant) from the RT analysis, with an average of 45 trials per participant (range 17 - 74) included in the analysis in each within subject condition (i.e., cue-target interval and trial sequence).

Main Analysis

The main analysis involved using all trials regardless of whether they involved a repetition or non-repetition of item (stimulus and response) from trial n – 2 to n, with the within-subjects factors of trial sequence (ABA vs CBA) and cue-target interval (500ms vs 1000ms) and the between-subjects factor of instruction-type (task-instruction vs mapping-instruction). The ANOVA results from the main analysis are detailed in full. See Table 1 for means and standard deviations.

[2] Access to the data from all experiments in this article can be requested from L. Prosser at l.prosser@outlook.com

Item-transition analysis

Two further analyses were performed, also assessing the *n* – 2 repetition cost according to instruction-type and cue-target interval, but taking into account the item-transition value of ABA trial sequences. One analysis included ABA trial sequences where there was item-repetition from trial *n* – 2 to *n*; the other analysis included ABA trial sequences where there was item-change from trial *n* – 2 to *n*. The item-repetition ABA trial sequences remove episodic mismatch as a confounding variable but include any item-level as well as task-level effects. The item-change ABA trial sequences do not exclude episodic mismatch as a confounding variable but do relate exclusively to task level effects. It should be noted that all CBA trial sequences were used for all analyses, since with the current design they necessarily always involved item-changes. The factors were the same as the main analysis: trial sequence (ABA vs CBA) and cue-target interval (500ms vs 1000ms) and the between-subjects factor of instruction-type (task-instruction vs mapping-instruction). For these analyses, only the key interactions (i.e., between trial sequence and instruction-type) are detailed in the text, but see Table 2 for all means and standard deviations.

Results

Main Analysis

Reaction time

The 2 x 2 x 2 ANOVA showed a significant main effect of cue-target interval, $F(1,70) = 97.81$, $p < .001$, $\eta_p^2 = .583$, with slower RTs with 500ms cue-target interval than 1000ms cue-target interval. The main effect of instruction-type was also significant, $F(1,70) = 30.51$, $p < .001$, $\eta_p^2 = .304$, with the task-instruction group having faster RTs than the mapping-instruction group, likely caused by the ability to prepare for the upcoming task due to having informative cues. The main effect of trial sequence was significant, $F(1,70) = 4.95$, $p = .029$,

η_p^2 = .006, with ABA task sequences being faster overall than CBA task sequences.

Cue-target interval and instruction-type interacted, $F(1,70) = 39.45$, $p < .001$, $\eta_p^2 = .36$, with cue-target interval having a bigger effect on response speed in the task-instruction group than in the mapping-instruction group, again likely caused by the ability to prepare the appropriate task in the task-instruction group. Cue-target interval did not interact with trial sequence, $F(1,70) = 0.09$, $p = .762$, $\eta_p^2 = .001$ and there was no 3–way interaction, $F(1,70) = 0.007$, $p = .934$, $\eta_p^2 < .001$.

Importantly, trial sequence and instruction-type interacted, $F(1,70) = 10.85$, $p = .002$, $\eta_p^2 = .134$, with the mapping-instruction group having a significant $n - 2$ repetition benefit, $t(35) = 4.51$, $p < .001$, and the task-instruction group having a very small non-significant $n - 2$ repetition cost, $t(35) = .654$, $p = .518$ (see Fig. 3 and Table 1). The presence of an $n - 2$ repetition benefit in the response-mappings group suggests that repeating a recent task facilitates performance in that group. The absence of such a facilitation in the task-instruction group suggests that something may be acting against the underlying facilitation effect that cancels it out in that group. Hence, this result may indicate the presence of backward inhibition in the task-instruction group.

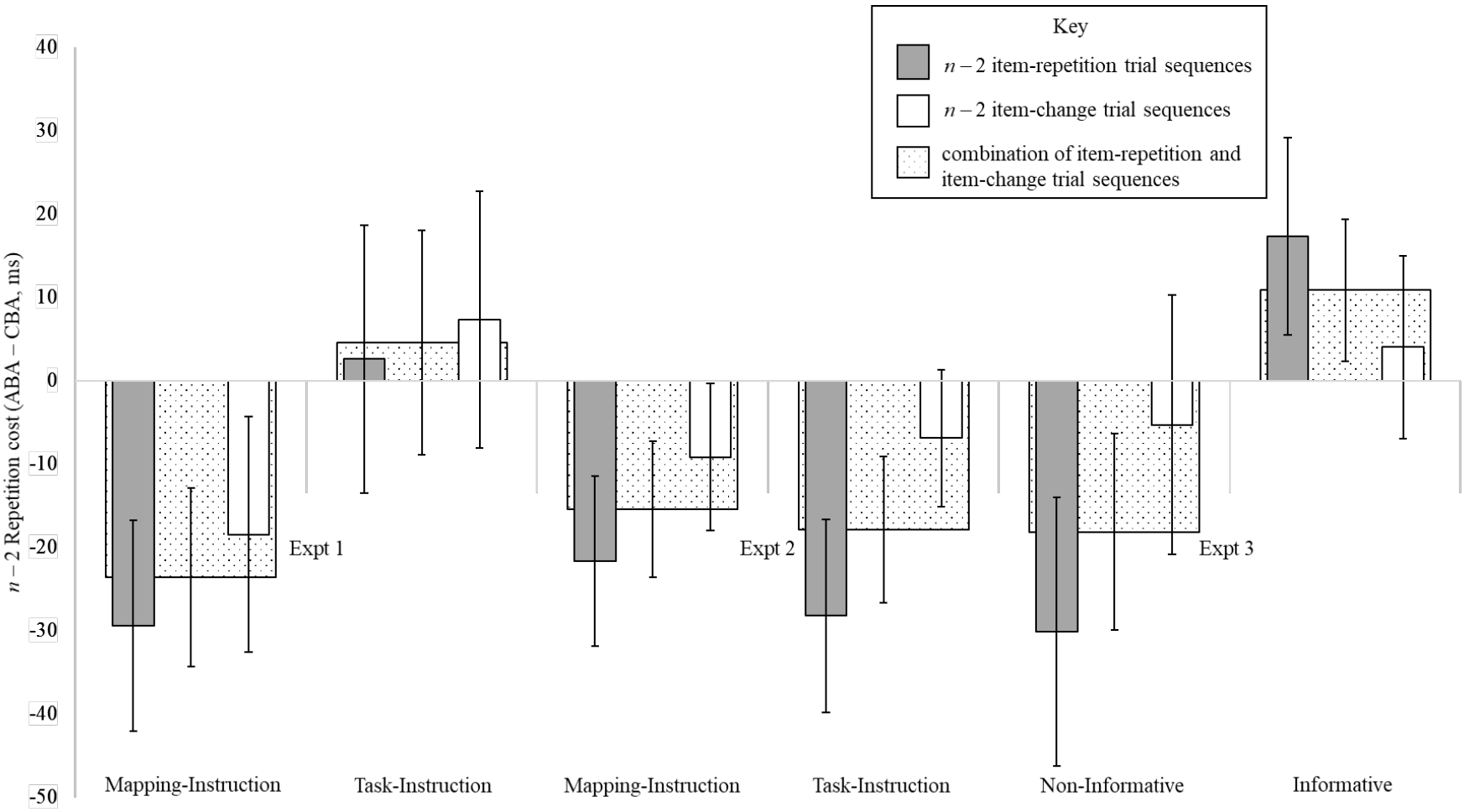

Figure 3. Mean RT *n* – 2 repetition cost for Experiments 1, 2 and 3 spilt by group/cue type (Expt. 1 and 2: Mapping-Instructions and Task-Instruction, Expt. 3: Informative and Non-Informative cues). Grey bars represent *n* – 2 item-repetition trial sequences, white bars represent *n* – 2 item-change trial sequences, dotted bars represent the combination of item-repetition and item-change trial sequences. Error bars represent 95% confidence intervals. N.B. separate error bars are shown for each condition (item-repetition, combined, item-change), centrally within each bar.

Table 1

RT (ms) and error (%) means and standard deviations (SD) for CBA and ABA trial sequences and means and 95% confidence intervals (CI) for the n - 2 repetition cost in Experiment 1, 2 and 3.

	Group	CTI	CBA (SD)	ABA (SD)	*n* - 2 repetition cost (ABA - CBA)	
					Mean	95% CI
			RT (ms)			
Expt 1	Task-Instruction	500	619.94 (86.43)	623.65 (78.6)	3.71	[-15.52, 22.94]
		1000	547.22 (101.65)	552.64 (84.39)	5.42	[-10.32, 21.16]
	Mapping-Instruction	500	721.46 (100.68)	696.40 (96.94)	-25.06	[-41.81, -8.31]
		1000	703.92 (106.33)	681.85 (90.28)	-22.07	[-38.08, -8.07]
			Error (%)			
	Task-Instruction	500	3.96 (4.29)	5.59 (4.33)	1.63	[0.40, 2.85]
		1000	3.96 (3.49)	3.89 (2.90)	-0.07	[-1.40, 1.26]
	Mapping-Instruction	500	7.36 (5.36)	6.15 (4.68)	-1.21	[-2.81, 0.39]
		1000	6.23 (4.63)	5.14 (4.26)	-1.09	[-2.29, 0.11]
	Group	CTI	CBA (SD)	ABA (SD)	*n* - 2 repetition cost (ABA - CBA)	
					Mean	95% CI
			RT (ms)			
Expt 2	Task-Instruction	500	722.18 (113.84)	705.31 (104.25)	-16.87	[-29.35, -4.39]
		1000	709.26 (110.22)	692 (106.89)	-19.64	[-28.15, -11.12]
	Response-Mappings	500	723.78 (123.26)	706.64 (104.26)	-17.14	[-28.01, -6.26]
		1000	705.8 (116.32)	689.62 (104.36)	-13.81	[-24.38, -3.23]
			Error (%)			
	Task-Instruction	500	5.92 (4.65)	5.92 (4.43)	0.00	[-0.65, 0.65]
		1000	5.29 (4.48)	5.32 (4.34)	0.04	[-0.8, 0.87]
	Mapping-Instruction	500	5.59 (3.81)	5.74 (3.88)	0.16	[-0.62, 0.93]
		1000	5.33 (3.44)	4.91 (3.91)	-0.42	[-1.41, 0.57]
	Cue Type	Block Order	CBA (SD)	ABA (SD)	*n* - 2 repetition cost (ABA - CBA)	
					Mean	95% CI
			RT (ms)			
Expt 3	Informative	Informative First	598.96 (95.21)	607.39 (102.08)	8.43	[-2.35, 19.21]
		Non-Informative First	564.69 (105.72)	578.04 (109.39)	13.34	[-0.95, 27.64]
	Non-Informative	Informative First	645.88 (73.72)	625.61 (79.9)	-20.27	[-34.63, -5.9]
		Non-Informative First	649.03 (85.55)	633.02 (92.54)	-16.01	[-36.35, 4.33]
			Error (%)			
	Informative	Informative First	4.77 (3.34)	4.95 (3.76)	0.18	[-0.92, 1.27]
		Non-Informative First	7.01 (5.73)	7.94 (5.55)	0.93	[-0.97, 2.84]
	Non-Informative	Informative First	4.81 (2.47)	5.51 (3.76)	0.70	[-0.57, 1.98]
		Non-Informative First	6.11 (4.61)	6.06 (5.13)	-0.06	[-1.5, 1.39]

Percentage error

The 2 x 2 x 2 ANOVA showed a significant main effect of cue-target interval, $F(1,70) = 6.27$ $p = .015$, $\eta_p^2 = .082$, with 500ms cue-target interval producing more errors than 1000ms cue-target interval. The main effect of instruction-type was also significant, $F(1,70) = 5.32$, $p = .024$, $\eta_p^2 = .071$, with the task-instruction group having fewer errors than the mapping-instruction group. The main effect of trial sequence was not significant, $F(1,70) = 0.326$, $p = .570$, $\eta_p^2 = .005$. The interactions involving cue-target interval were not significant, cue-target interval and instruction-type: $F(1,70) = 0.084$, $p = .773$, $\eta_p^2 = .001$, cue-target interval and trial sequence: $F(1,70) = 1.37$, $p = .246$, $\eta_p^2 = .019$, 3-way: $F(1,70) = 1.81$, $p = .182$, $\eta_p^2 = .025$.

The key interaction between trial sequence and instruction-type was again significant, $F(1,70) = 8.66$, $p = .004$, $\eta_p^2 = .110$, with the mapping-instruction group having a significant $n - 2$ repetition benefit, $t(35) = 2.58$, $p = .014$, and the task-instruction group having a non-significant $n - 2$ repetition cost, $t(35) = 1.68$, $p = .102$. This pattern is equivalent to that in the RT data, see Table 1.

Item-transition analysis

The key interaction result of trial sequence and instruction-type was significant (and showed the same pattern as for the overall analysis) in both the item-repetition, $F(1,70) = 10.23$, $p = .002$, $\eta_p^2 = .128$, and item-change, $F(1,70) = 5.78$, $p = .019$, $\eta_p^2 = .076$, ANOVAs for the RT analysis. The same was true for the percentage error analysis: item-repetition, $F(1,70) = 5.89$, $p = .018$, $\eta_p^2 = .078$; item-change, $F(1,70) = 4.23$, $p = .043$, $\eta_p^2 = .0$

Table 2

RT (ms) and error (%) means and standard deviations (SD) for ABA trial sequences spilt by item-transition (item-repetition (A_1BA_1) and item-change (A_2BA_1)) and means and 95% confidence intervals (CI) for the associated n - 2 repetition costs in Experiment 1, 2 and 3.

	Group	CTI	A_1BA_1 (SD)	*n* - 2 repetition cost (A_1BA_1 - CBA)		A_2BA_1 (SD)	*n* - 2 repetition cost (A_2BA_1 - CBA)	
				Mean	95% CI		Mean	95% CI
				RT (ms)				
Expt 1	Task-Instruction	500	620.70 (86.12)	0.76	[-23.95, 25.46]	625 (82.98)	5.06	[-13.07, 23.20]
		1000	553.96 (87.1)	6.74	[-12.59, 26.07]	553.55 (97.47)	6.34	[-12.67, 25.34]
	Mapping-Instruction	500	684.26 (107.86)	-37.19	[-56.61, -17.77]	708.44 (98.34)	-13.02	[-34.48, 8.45]
		1000	682.32 (106.29)	-21.60	[-37.28, -5.93]	679.57 (84.13)	-24.35	[-45.18, -3.52]
				Error (%)				
	Task-Instruction	500	6.22 (5.84)	2.26	[0.50, 4.02]	4.99 (4.56)	1.03	[-0.44, 2.49]
		1000	3.52 (3.72)	-0.44	[-2.02, 1.14]	4.10 (3.98)	0.15	[-1.58, 1.87]
	Mapping-Instruction	500	6.13 (5.11)	-1.23	[-3.26, 0.80]	6.06 (6.19)	-1.30	[-3.16, 0.56]
		1000	5.06 (5.49)	-1.17	[-2.89, 0.55]	5.25 (5.05)	-0.98	[-2.53, 0.58]
	Group	CTI	A_1BA_1 (SD)	*n* - 2 repetition cost (A_1BA_1 - CBA)		A_2BA_1 (SD)	*n* - 2 repetition cost (A_2BA_1 - CBA)	
				Mean	95% CI		Mean	95% CI
				RT (ms)				
Expt 2	Task-Instruction	500	696.84 (103.7)	-25.34	[-39.47, -11.22]	714.55 (108.16)	-7.63	[-21.67, 6.41]
		1000	677.76 (103.81)	-31.50	[-43.62, -19.38]	702.36 (109.99)	-6.90	[-15.95, 2.15]
	Response-Mappings	500	696.21 (104.91)	-27.57	[-40.12, -15.03]	717.12 (105.64)	-6.66	[-18.9, 5.58]
		1000	689.84 (104.68)	-15.96	[-28.11, -3.82]	694.77 (111.89)	-11.03	[-23.31, 1.25]
				Error (%)				
	Task-Instruction	500	5.57 (4.47)	-0.35	[-1.17, 0.46]	6.24 (5.37)	0.32	[-0.69, 1.33]
		1000	5.03 (4.55)	-0.26	[-1.57, 1.05]	5.59 (5.03)	0.30	[-0.51, 1.11]
	Mapping-Instruction	500	6.39 (4.5)	0.81	[-0.24, 1.85]	5.21 (4.37)	-0.38	[-1.38, 0.62]
		1000	4.64 (4.42)	-0.69	[-1.9, 0.53]	5.16 (4.41)	-0.17	[-1.36, 1.01]
	Cue Type	Block Order	A_1BA_1 (SD)	*n* - 2 repetition cost (A_1BA_1 - CBA)		A_2BA_1 (SD)	*n* - 2 repetition cost (A_2BA_1 - CBA)	
				Mean	95% CI		Mean	95% CI
				RT (ms)				
Expt 3	Informative	Informative First	614.96 (100.69)	15.99	[1.69, 30.3]	599.17 (108.92)	0.20	[-17.17, 17.57]
		Non-Informative First	583.33 (112.39)	18.64	[-1.77, 39.04]	572.59 (108.22)	7.89	[-7.12, 22.91]
	Non-Informative	Informative First	615.23 (77.18)	-30.65	[-54.37, -6.93]	636.01 (93.23)	-9.87	[-26.54, 6.8]
		Non-Informative First	619.39 (101.06)	-29.64	[-54, -5.29]	648.32 (96.5)	-0.71	[-28.86, 27.44]
				Error (%)				
	Informative	Informative First	5.06 (4.07)	0.29	[-1.05, 1.62]	4.75 (4.39)	-0.02	[-1.7, 1.65]
		Non-Informative First	8.47 (6.31)	1.46	[-0.47, 3.39]	7.49 (6.06)	0.48	[-2.09, 3.05]
	Non-Informative	Informative First	4.71 (3.7)	-0.09	[-1.66, 1.47]	6.18 (4.6)	1.38	[-0.28, 3.04]
		Non-Informative First	6.67 (5.44)	0.55	[-1.05, 2.15]	5.42 (5.42)	-0.70	[-2.39, 0.1]

Discussion

The main aim of this experiment was to see whether evidence of backward inhibition can be observed without a reason for a reactive cognitive control mechanism to be applied, i.e., conflict between tasks being present. We did not find a significant *n* – 2 repetition cost[3] in the task-instruction group, so in that respect we did not replicate Costa and Friedrich's (2012) result. However, we did find a significant interaction (in both RT and PE) between instruction-type and trial sequence, with the mapping-instruction group showing a significant *n* – 2 repetition benefit that was absent in the task-instruction group. As explained below, this result could be indicative of backward inhibition in the task-instruction group counteracting the effect of facilitation that is clearly shown in the mapping-instruction group. As such, it may lend some support to Costa and Friedrich's suggestion that no sharing of stimuli or responses between tasks is necessary to cause backward inhibition. The interaction between instruction-type and trial sequence on item-change sequences might indicate that backward inhibition occurred at the level of tasks, although it could potentially reflect an episodic mismatch effect (Gade et al., 2017; Grange et al., 2017). The same interaction on item-repetition sequences however, whilst potentially only indicating item-level backward inhibition, cannot be due to episodic mismatch.

[3] A factor which might have affected the size of the *n* – 2 repetition cost within this experiment is that task repetitions were allowed. Previous research has found that the *n* – 2 repetition cost is reduced when task repetitions are allowed (Gade et al., 2017; Philipp & Koch, 2006; Scheil & Kleinsorge, 2018). It should be noted however, that Costa and Friedrich (2012) also included task repetitions in their design, and so including them does not explain why we do not replicate their finding.

Grange, Juvina, and Houghton (2013) suggested, on the basis of computerised modelling work, that if no backward inhibition has occurred then there should be an *n* – 2 repetition benefit and not just a lack of significant *n* – 2 repetition cost. They ran three models that involved different levels of inhibition. One model included inhibition at a low level: this model produced *n* – 2 repetition costs that were indistinguishable from zero. The authors concluded that "a null *n* – 2 repetition cost provides no evidence on its own for an absence of inhibition" (Abstract). Applying the same logic to our own result, we might conclude that the absence of a significant *n* – 2 repetition cost in the task-instruction group need not necessarily indicate the absence of backward inhibition; instead, the *lack of an n – 2 repetition benefit* in the task-instruction group, especially where there is one for the mapping-instruction group, could plausibly signal the presence of an inhibitory effect (backward inhibition) counteracting an underlying facilitation and reducing it to zero.

We postulate that the instruction-type difference in *n* – 2 repetition effects (plausibly indicating inhibition, as explained above) is likely to stem from the differences in experimental set-up between the instruction-types (i.e., learning three tasks and their associated cues compared to six response mappings). Costa and Friedrich put the presence of their backward inhibition effect down to participants applying backward inhibition at the time of processing the pre-target task-cue (i.e., in a proactive way), and it may be that in our Experiment 1 also it was the trial-by-trial task cues that led to the instruction-type difference in the trial-sequence effect that we have suggested may indicate backward inhibition. An alternative possibility, however, is that simply instructing participants to switch between tasks might encourage them to use backward inhibition to facilitate that switching, even though the univalent nature of the stimuli and responses would seem to mean that it would not actually have been necessary to do so in this case.

Experiment 2

In this experiment we tested whether simply instructing participants to perform and switch between three separate tasks would be sufficient to generate the instruction-type difference found in Experiment 1. Therefore, in Experiment 2 we removed trial-by-trial cueing from the task-instruction group, with both groups now being presented only with a fixation cross before the target stimuli on all trials. We predicted that (as in Expt. 1) there would again be a significant *n* – 2 repetition benefit in the mappings-instruction group. More importantly, if giving instructions based around tasks was sufficient to drive a backward inhibition effect, then we should also see a significant difference between instruction-types in terms of the *n* – 2 repetition effect, with a significantly reduced benefit (potentially becoming an *n* – 2 repetition cost) in the task-instruction group. If trial-by-trial cueing is necessary to drive the backward inhibition effect however, then we would expect to see facilitation rather than a cost in both instruction-types.

Methods

Participants

Eighty-four participants were tested in total for either course credit or £5 compensation for their time. One participant was excluded for accuracy below 70% and one participant was excluded due to having more than 10% of trials removed for too slow and/or too fast responses; a further two participants were excluded to maintain matching.

In the task-instruction group there were 40 participants aged between 17 and 41 years (mean age 22.5 years; 31 females) and in the mapping-instruction group there were 40 participants aged between 17 and 48 years (mean age 21.6 years; 32 females).

Materials

The tasks and stimuli were the same as Experiment 1 apart from that neither instruction-type group was presented with cue words; instead, a fixation cross was shown for either 500ms or 1000ms prior to the target being presented (see Fig. 2).

Procedure

The procedure mirrored that of Experiment 1, apart from that the length of the experiment was increased so that instead of 10 blocks participants completed 30 experimental blocks. This increase in length was to add more precision to the scores used in the item-repetition analysis. For the mapping-instruction group the instructions were the same as in Experiment 1. For the task-instruction group the instructions omitted the information about cues that was presented in Experiment 1 but still presented the responses in terms of their respective tasks. I.e., participants were informed of the colour task and then shown the red and green stimuli and their respective response buttons, etc.

Design & Analysis

Main Analysis

The data exclusion procedure was the same as Experiment 1. On average 44% of trials sequences were the trial sequences of interest (max: 49%, min: 41%). Of the trials of interest on average 16% were excluded from the RT analysis per participant. For the main analysis (i.e., not split by item-transition) there was an average of 133 trials per participant (range 53 – 178) in each within subject condition (i.e., cue-target interval and trial sequence).

An ANOVA with within-subjects factors of trial sequence (ABA vs CBA) and cue-target interval (500ms vs 1000ms) and the between-subjects factor of instruction-type (task-instruction vs mapping-instruction) was run on both RT and PE data. The full results are reported below. See Table 1 and Fig. 3 for means and standard deviations.

Item-transition analysis.

As in Experiment 1, two further ANOVA were run. These ANOVAs used the same factors as the main analysis but split the ABA trial sequences by item-transition: item-repetition and item-change. Only the key interactions (i.e., between trial sequence and instruction-type) are reported below (see Table 2 and Fig. 3).

Between experiment main analysis

In order to compare results between experiments, a planned four-way ANOVA with the added variable of Experiment (1 vs 2) was run. This ANOVA directly investigated the effects of removing task-cues. If the availability of task-cues is responsible for the presence of a backward inhibition effect, then there should be a 3-way interaction of experiment, trial sequence and instruction-type. Specifically, we would expect to see that the two-way interaction of trial sequence and instruction-type seen in Experiment 1 would be absent in Experiment 2, where instead both instruction-types would show evidence of facilitation. Only the effects involving experiment are reported for this analysis.

Between experiment item-transition analysis

Again, we split all ABA trials by whether the item repeated from trial *n – 2* to *n* (item-repetition) or not (item-change) for the between experiment analysis and ran a further two ANOVAS. Only the key interactions (i.e., between trial sequence, instruction-type and experiment) are reported below.

Results

Main Analysis

Reaction time

The 2 x 2 x 2 ANOVA showed a significant main effect of cue-target interval, $F(1,78) = 41.44$, $p < .001$, $\eta_p^2 = .347$; RTs were slower with only 500ms cue-target interval than with 1000ms cue-target interval. The main effect of trial sequence was significant, $F(1,78) = 32.07$, $p < .001$, $\eta_p^2 = .291$, with ABA task sequences being faster overall than CBA task sequences. The main effect of instruction-type was not significant, $F(1,78) < .001$, $p = .985$, $\eta_p^2 < .001$.

The interactions between cue-target interval and instruction-type, $F(1,78) = 0.18$, $p = .675$, $\eta_p^2 = .002$, and between cue-target interval and trial sequence, $F(1,78) = 0.004$, $p = .951$, $\eta_p^2 < .001$, along with the 3–way interaction, $F(1,78) = 0.45$, $p = .503$, $\eta_p^2 = .006$, were not significant. Importantly, in this experiment the interaction of trial sequence and instruction-type, $F(1,78) = 0.22$, $p = .642$, $\eta_p^2 = .003$, was not significant. Both the mapping-instruction and task-instruction groups showed significant $n - 2$ repetition benefits, $t(39) = 3.815$, $p < .001$, and $t(39) = 4.107$, $p < .001$, respectively.

Percentage Error

The 2 x 2 x 2 ANOVA showed a significant main effect of cue-target interval, $F(1,78) = 7.08$, $p = .009$, $\eta_p^2 = .083$, with more errors with only 500ms cue-target interval than 1000ms cue-target interval. The main effect of trial sequence was not significant, $F(1,78) = 0.09$, $p = .766$, $\eta_p^2 = .001$. The main effect of instruction-type was not significant, $F(1,78) = 0.09$, $p = .795$, $\eta_p^2 = .001$.

The interaction between cue-target interval and instruction-type, $F(1,78) = 0.02$, $p = .880$, $\eta_p^2 < .001$, and between cue-target interval and trial sequence, $F(1,78) = 0.42$, $p = .520$, $\eta_p^2 = .005$, along with the 3–way interaction, $F(1,78) = 0.55$, $p = .460$, $\eta_p^2 = .005$, were not significant. Additionally the key interaction of trial sequence and instruction-type, $F(1,78) = 0.14$, $p = .705$, $\eta_p^2 = .002$, was not significant.

Item-transition analysis

For the two 2 x 2 x 2 ANOVAs where ABA trial sequences were split by item-transition, the key interaction of trial sequence and instruction-type was not significant in either the item-repetition, $F(1,78) = 0.762$, $p = .385$, $\eta_p^2 = .01$, or the item-change, $F(1,78) = 0.07$, $p = .793$, $\eta_p^2 = .001$, ANOVA for the RT analysis. Additionally, in the percentage error analysis the key interaction of trial sequence and instruction-type was not significant in either the item-repetition, $F(1,78) = 0.356$, $p = .552$, $\eta_p^2 = .005$, or item-change, $F(1,78) = 1.432$, $p = .235$, $\eta_p^2 = .018$, ANOVA.

Between experiment main analysis

In Experiment 1 there was an indication of backward inhibition in the task-instruction group as demonstrated by the interaction of trial sequence and instruction-type (with the facilitation present in the mapping-instruction group being absent in the task-instruction group). In Experiment 2 there was no interaction of trial sequence and instruction-type, with facilitation in both groups.

We now wish to determine whether this pattern of results constitutes a significant difference between experiments, as such a difference would be convincing evidence that the provision of task-cues in Experiment 1 had prevented an $n - 2$ repetition benefit from being present in the task-instruction group. Hence, a four-way ANOVA was conducted, with the factors experiment (1, 2: between subjects factor), instruction-type (mapping-instruction group, task-

instruction group: between subjects factor), trial sequence (ABA, CBA: within subjects factor) and cue-target interval (500ms, 1000ms: within subjects factor).

The key interaction of interest was the three-way interaction of trial sequence, instruction-type and experiment. This interaction was significant in both the RT analysis, $F(1,148) = 9.10$, $p = .003$, $\eta_p^2 = .058$, and in the PE analysis, $F(1,148) = 5.65$, $p = .019$, $\eta_p^2 = .037$. (Note that the breakdown of this interaction by experiment constitutes the main analyses reported above for Experiments 1 and 2.) This three-way interaction provides evidence that the provision of task cues in Experiment 1 was responsible for the finding in that experiment whereby an $n - 2$ repetition benefit, present in the response-mappings group, was absent in the task-instruction group. As explained above, this pattern of effects constitutes tentative evidence of backward inhibition driven by task-cues.

Between experiment item-transition analysis

The key interaction result of trial sequence, instruction-type and experiment was significant in both the item-repetition, $F(1,148) = 9.83$, $p = .002$, $\eta_p^2 = .062$, and item-change, $F(1,148) = 3.93$, $p = .049$, $\eta_p^2 = .026$, ANOVAs for the RT analysis. In the PE analysis the key interaction of trial sequence, instruction-type and experiment was significant in the item-repetition ANOVA, $F(1,148) = 5.573$, $p = .020$, $\eta_p^2 = .036$, where it was modified by a significant but not predicted 4-way interaction including cue-target interval, $F(1,148) = 4.945$, $p = .028$, $\eta_p^2 = .032$; the three-way interaction was not significant in the item-change ANOVA $F(1,148) = 1.442$, $p = .232$, $\eta_p^2 = .010$.

Discussion

The main question for this experiment was whether task instructions are enough to cause backward inhibition to occur. In Experiment 2, both the task-instruction and mapping-

instruction groups showed a significant facilitation effect of returning to a recently performed task. This is what would be expected if no backward inhibition had been applied. Therefore, the interaction between trial sequence and instruction-type seen in Experiment 1, which indicated that backward inhibition might be present, was not replicated here. The results of Experiment 2, therefore, provide no evidence that simply instructing participants to perform and switch between three separate tasks (as opposed to performing according to a single large set of learned stimulus-response mappings) is sufficient to cause backward inhibition. Instead, it seems more likely that the provision of task-cues had been responsible for the instruction-type group difference seen in Experiment 1 that we suggested might reflect backward inhibition. The between-experiments analysis supports the idea that task-cues were the critical difference between Experiments 1 and 2. Hence, between task conflict does not seem to be necessary for backward inhibition to be present, but instead tasks cues do appear to be necessary (at least when stimuli and responses are univalent).

It should be noted that it is not necessarily the case that participants used the instructions in the way we had anticipated they might. After the testing sessions in Experiments 1 and 2, participants were asked to state whether they had been thinking mainly in terms of: i) six stimulus-response mappings or ii) three tasks (colour, line and shape). Their responses were not closely in line with their assigned instruction-type group[4]. Therefore, we cannot discount the possibility that instructions (without trial by trial cueing)

[4] Number (N) of participants giving each answer were as follows. Expt. 1: Response-mapping group (N = 36): mappings, N = 8; tasks, N = 20; other, N = 8. Task-instruction group (N = 36): mappings, N = 10; tasks, N = 24; other, N = 2. Expt. 2: Response-mapping group (N = 40): mappings, N = 13; tasks, N = 20, other, N = 7. Task-instruction group: (N = 40): mappings, N = 20; tasks, N = 15; other, N = 5.

could be enough in principle to cause backward inhibition to be applied, even though we found no evidence for an effect of instructions here. The important point to note though is that the results of Experiment 2 indicate that the instruction-type group difference found in Experiment 1 in terms of the *n* – 2 repetition effect do not seem to have been produced by the difference in instructions used in that experiment.

The item-transition analyses indicate that episodic mismatch did not confound any of the effects reported, since the results of the main analysis were replicated in the item-repetition analysis. We do not yet have strong evidence for a specific effect of cueing on task-level backward inhibition per se, since although the item-change part of the between-experiment item-transition analysis reached significance for RTs, this was only just the case ($p = .049$), and there was no significant effect of experiment on the *n* – 2 repetition effect in terms of errors on item-change trials.

Experiment 3 was designed to provide a more direct and powerful test of the hypothesis that the provision of task-cues can drive backward inhibition at either the task-level or the item-level with univalent stimuli and responses.

Experiment 3

The aim of this experiment was to test whether task cues are sufficient to produce backward inhibition when stimuli and responses are univalent. All participants were given the instructions to perform and switch between tasks that had been given to the task-instruction groups of Experiments 1 and 2. We introduced a between-blocks manipulation of whether or not cues were informative with respect to the current trial for all participants. If trial-by-trial task-cueing is necessary and sufficient to produce backward inhibition when there is no apparent between-task conflict, then we should find evidence of backward inhibition in the informative cue blocks and not in the non-informative cue blocks.

Methods

Participants

Forty participants were tested in total for either course credit or £5 compensation for their time. One participant was excluded for accuracy less than 70% and three participants were excluded due to having more than 10% of trials removed for responses lower than 200ms or higher than 2000ms.

In the group of participants who were presented with the informative-cues condition first there were 18 participants aged between 18 and 29 years (mean age 21.7 years; 14 females) and in the group of participants who were presented with the non-informative-cues first there were 18 participants aged between 19 and 30 years (mean age 22.7 years; 14 females).

Materials

The tasks and stimuli were the same as Experiments 1 and 2 apart from a few key changes. Task repetitions were removed to increase viable trial numbers: i.e., every trial involved a switch in task (so every trial was either ABA or CBA). Additionally, response mappings were no longer counterbalanced, in order to simplify the testing procedure and to reduce the number of participant exclusions required to maintain matching: instead, every participant used the mapping (from button 1 to 6): red, vertical, triangle, green, horizontal, circle (as in Fig. 1).

All participants experienced both of the conditions, with half of each participant's experimental session using informative cues (COLOUR, LINE, SHAPE) and the other half non-informative cues (DDDDDD, BBBB, JJJJJ). The non-informative cues were randomly selected on each trial (excluding immediate repetitions). The order of the session-halves was

counterbalanced, so half of the participants had the informative cue blocks before the non-informative cue blocks, and the other half of participants had the reverse order.

Procedure

The procedure was similar to that used for the task-instruction group in the previous experiments, apart from the following minor changes. Practice involved using the cue type appropriate for the coming block, and followed the same format as for the task-instruction groups in Experiments 1 and 2. In each session-half, the experimental blocks consisted of seven blocks of 50 trials. A second round of practice with the new cue type was presented before the experimental blocks of the second session-half. Only one cue-target interval (1000ms) was used, since no consistent effect of cue-target interval was present in the two previous experiments. Additionally, the response-cue interval was reduced to 50ms since it has been suggested that a small response-cue interval can increase the size of backward inhibition (Scheil & Kleinsorge, 2014), and a bigger backward inhibition effect should make any changes in the size of the effect due to cueing more apparent. See Fig. 2 for an example trial.

Design & Analysis

Main Analysis

The data exclusion procedure was the same as Experiment 1. Of the trials of interest on average 17% were excluded from the RT analysis per participant. For the main analysis (i.e., not split by item-transition) an average of 140 trials per participant (range 60 - 223) were included in the analysis in each within subject condition (i.e., cue type and trial sequence).

RT and percentage error data were analysed by ANOVA, with within-subjects factors of trial sequence (ABA vs CBA) and cue type (informative vs non-informative) and the between-subjects factor of order (informative-cues first vs non-informative-cues first).

Item-transition analysis

As in Experiment 1 and 2, two further ANOVAs were run using the same factors as in the main analysis but with ABA trial sequences being split by item-transition: item-repetition and item-change. Only the key result of the trial sequence by cue type interaction is reported.

Results

Main analysis

Reaction time

The 2 x 2 x 2 ANOVA showed a significant main effect of cue-type, $F(1,34) = 22.62$, $p < .001$, $\eta_p^2 = .400$, with slower RTs for non-informative cues than for informative cues. The main effect of trial sequence was not significant, $F(1,34) = 0.92$, $p = .345$, $\eta_p^2 = .026$. The main effect of order was not significant, $F(1,34) = 0.21$, $p = .649$, $\eta_p^2 = .006$. The interaction of cue-type and order, $F(1,34) = 2.98$, $p = .093$, $\eta_p^2 = .081$, and trial sequence and order, $F(1,34) = 0.37$, $p = .549$, $\eta_p^2 = .011$, and the 3–way interaction, $F(1,34) = 0.002$, $p = .963$, $\eta_p^2 < .001$, were not significant. Importantly, as predicted the interaction between trial sequence and cue-type was significant, $F(1,34) = 17.41$, $p < .001$, $\eta_p^2 = .339$. There was a significant *n* – 2 repetition cost with informative cues, $t(35) = 2.59$, $p = .014$, whereas non-informative cues produced a significant *n* – 2 repetition benefit, $t(35) = 3.11$, $p = .004$.

Percentage error

For the percentage error 2 x 2 x 2 ANOVA, no main effects or interactions were significant, cue-type: $F(1,34) = 1.45$, $p = .236$, $\eta_p^2 = .041$, trial sequence: $F(1,34) = 1.54$, $p = .224$, $\eta_p^2 = .043$, order: $F(1,34) = 1.82$, $p = .187$, $\eta_p^2 = .051$, cue-type and order: $F(1,34) = 3.47$, $p = .071$, $\eta_p^2 = .092$, trial sequence and order: $F(1,34) < .001$, $p = .999$, $\eta_p^2 < .001$, trial sequence and cue-type: $F(1,34) = 0.12$ $p = .735$, $\eta_p^2 = .003$, 3–way: $F(1,34) = 1.25$, $p = .271$, $\eta_p^2 = .036$.

Item-transition analysis

For the RT analysis, the key interaction of trial sequence and cue type was significant for item-repetition trials, $F(1,34) = 29.63$, $p < .001$, $\eta_p^2 = .466$, but it was not significant for item-change trials, $F(1,34) < .001$, $p = .311$, $\eta_p^2 = .03$. This pattern of results suggests that the effect of cue-type on the *n* – 2 repetition effect is likely to occur at the item level rather than the task level. For the PE analysis, the key interaction of trial sequence and cue type was not significant for item-repetition trials, $F(1,34) = 0.63$, $p = .433$, $\eta_p^2 = .018$, or item-change trials, $F(1,34) = 0.02$, $p = .903$, $\eta_p^2 < .001$.

Discussion

The results of Experiment 3 supported the hypothesis that task-cues can cause backward inhibition in a paradigm involving no shared stimuli or responses. This hypothesis stemmed from the finding in Experiment 1 that an *n* – 2 repetition benefit for the mapping-instruction group was absent for the task-instruction group, suggesting that it had been counteracted by inhibition (cf. Grange et al., 2013), together with there being a benefit in both groups in Experiment 2 where there were no task cues, narrowing down the likely cause of the original effect to cues rather than instructions. The pattern of results in Experiment 3 is particularly clear: an *n* – 2 repetition *cost* (rather than just the absence of a benefit) was present in the blocks with informative task-cues, and an *n* – 2 repetition *benefit* with non-informative cues.

However, we note that the backward inhibition effect in Experiment 3 was only significant at the item level rather than at the task level – i.e., it was only present when the target and response for trial *n* had also been present on trial *n* – 2. Hence, the inhibition that is implied by the presence of a significant *n* – 2 repetition cost in cued blocks might only have been applied to the previously activated target and/or response, and not to the whole task. However, this also means that episodic mismatch is not inflating the cost reported.

General Discussion

The main aim of these experiments was to confirm whether evidence of a backward inhibition effect (i.e., an *n* – 2 repetition cost) could be found when participants switched between tasks even though no target stimuli or responses were shared between the tasks (i.e., all stimuli and responses were "univalent" with respect to task), as Costa and Friedrich (2012) had found previously, and to investigate why such an effect might exist. We found tentative evidence for backward inhibition in Experiment 1 (in the form of an abolished facilitation effect) and clear evidence for it in Experiment 3. This finding argues against backward inhibition being a purely reactive mechanism that is triggered by the detection of between-task conflict during task-performance – i.e., conflict generated at the stage of stimulus-processing and/or response-selection. There was no clear evidence for a task-level backward inhibition effect (i.e., an effect present on item-change trials), in that the tentative task-level backward inhibition effect in Experiment 1 was not replicated in Experiment 3. An item-level backward inhibition effect (i.e., present on item-repetition trials) was clearly evident, however. Its presence was associated with the presentation of informative task-cues prior to targets on each trial (Expt. 3), in line with suggestions that the cue-target translation process may be important in generating backward inhibition (Arbuthnott, 2005; Gade & Koch, 2014; Grange & Houghton, 2010; Houghton et al., 2009). This result suggests that task cues may drive backward inhibition when there is no between-task conflict generated by shared stimuli or responses. We found no indication that backward inhibition was driven by the instruction to perform and switch between separate tasks as opposed to simply applying a set of six stimulus-response mappings.

It has been suggested that backward inhibition is a reactive mechanism that is driven by the detection of conflict between tasks (Koch et al., 2010), its purpose being to suppress the activity of the currently greatest competitor for task-selection – i.e., the task that was most

recently used (cf. Mayr & Keele, 2000). Some accounts highlight a likely role of conflict detected *during task-performance* (i.e., when processing a task-stimulus in order to select a task-appropriate judgement or response) as being the main triggering conditions of backward inhibition (e.g. Gade & Koch, 2007; Sexton and Cooper, 2017; Schuch & Koch, 2003; Sdoia & Ferlazzo, 2012; Philipp et al., 2007; Koch et al., 2010). Our results, however, do not support the idea that conflict between tasks during task-performance is necessary for BI to be applied as we found backward inhibition without either shared stimuli or shared responses. For the same reasons, our results are not in line with Sexton and Cooper's (2017) computational model of task switching. That model is based upon the proposition that backward inhibition is a reactive mechanism triggered by conflict between task representations caused after cue processing is complete. Therefore our results, showing evidence of backward inhibition without shared stimuli or responses, presumably could not be produced by Sexton and Cooper's model.

Our results do not fit with Sexton and Cooper's (2017) model in two further ways. First, regarding cue-processing; and second, regarding item-level effects. Within our experiments, cues were required for the $n - 2$ repetition cost to be found, but as yet cue-processing is not a feature of Sexton and Cooper's model. Sexton and Cooper themselves comment that the model does not fully explain how conflict during cue processing contributes to the $n - 2$ repetition cost, highlighting evidence that the size of backward inhibition can reflect factors present at the task-preparation stage (e.g. cue-task-translation: Arbuthnott, 2005; Gade & Koch, 2014; Grange & Houghton, 2010; Houghton et al., 2009) and therefore these factors need to be taken into consideration. Our results corroborate this idea, and future versions of their model might usefully build in the role of cue-related processing.

It is worth noting at this point that although our current results might indicate the role of cue-task translation as driving inhibition of the previous task (or task-item) in a relatively direct way (e.g. during the translation process on a particular trial), it might not be as simple as that. A follow up study (based on the tasks/design of Experiment 3) manipulated cueing trial-by-trial, in that on any given trial participants could either be presented with an informative or non-informative cue. This follow up study found no indication that BI was applied as a result of cue presence on trial $n - 1$ or any other particular trial in a three-trial sequence (see Prosser, 2018), indicating that cue presence on a single trial is not enough to cause backward inhibition to be applied. Hence, presence of cues over a longer term (i.e., over multiple trials at least) may be important to drive the effect of cueing seen in the experiments reported here. However, how this might come about is currently unclear; hence, further study is needed into how and why task-cues might drive the backward inhibition effect.

Finally, the results from Experiment 3 show that inhibition was applied only to the stimulus/response that was used on the previous trial and not all stimuli/responses of the previous task, which means these results are showing inhibition at the item level. This result again would not fit with the Sexton and Cooper (2017) model as that model directs inhibition only towards tasks and not items. Backward inhibition is usually considered to be a task-level effect, even to the point that in some experiments feature repetitions (from $n - 2$ to n) are excluded from the design (Philipp, Jolicoeur, Falkenstein, & Koch, 2007; Schuch & Koch, 2003). However, one thing to note is that by removing feature repetitions from occurring, backward inhibition becomes potentially confounded with episodic mismatch. Thus, it can be questioned as to whether the results of such studies are purely inhibition related (cf. Gade et al. 2017; Grange et al. 2017). In contrast, as the n – 2 repetition cost in our Experiment 3 was item-level there is no episodic mismatch confound. Therefore, we can be confident that our

finding of an $n - 2$ repetition cost being present with univalent stimuli and responses only when informative cues are used is likely to reflect a true inhibition effect.

Conclusion

We conclude that backward inhibition (at least at the item-level) can be present *without* between-task conflict being present during performance, i.e., when stimuli and responses are not shared between tasks. A confound with episodic mismatch was excluded as a possible cause of this result. The backward inhibition effect was clearly associated with the presence of valid task-cues (between blocks), being completely absent when such cues were not presented. These data argue against task-conflict during performance (stimuli/response processing) being required to generate backward inhibition. Instead, they are consistent with the idea that backward inhibition can be generated proactively, during preparation of a task (cue processing).

The authors declare that there is no conflict of interest

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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