

## CONTEXT OF BACKWARD COMPATIBILITY EFFECTS

THE CONTEXTUAL SPECIFICITY OF BACKWARD COMPATIBILITY EFFECTS

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### Lay Abstract

Backward compatibility effects (BCEs) have been consistently observed in dual task paradigms. BCEs occur when Task 1 and Task 2 response information are congruent: participants respond faster to Task 1 when the two tasks require congruent responses than when they require incongruent ones. This suggests that there is some parallel processing of Task 2 while performing Task 1. The purpose of this study was to explore the episodic account of BCE development. Since episodic memories are context-specific, BCEs should also be context-specific, according to the episodic account. By manipulating the context of Task 2 learning, we tested whether this affected subsequent BCE development. Our findings suggest that context-specific disruption of BCE development is possible, but depends on other factors as well.

## Abstract

Dual task studies have found that Task 2 response information is activated during Task 1 response selection, and can have a priming effect on Task 1. This is called the backward compatibility effect (BCE). Giammarco et al. (2016) found that single-task practice of Task 2 in the context of a random, filler task (Practice-T2 condition) extinguished BCE development in a subsequent dual-task. On the other hand, practicing Task 2 in the context of Task 1 (Practice-Both condition) promoted BCE development in subsequent dual-tasks. Experiment 1a sought to replicate this context-specific disruption of BCE development by presenting participants with a single-task practice phase where they practiced Task 2 along with a filler task, and then observed BCE development in a subsequent dual-task phase. Experiment 1b addressed a counterbalancing issue in Experiment 1a. Experiment 2 was an exact replication of the Practice-T2 condition used in Giammarco et al. (2016). Overall, we conceptually replicated the context-specific disruption of BCE in Experiment 2, but not in Experiments 1a and 1b. Further study is warranted to determine the effect of specific response features on the learning context of Task 2.

*Keywords* : Psychological Refractory Period, dual-tasks, backward compatibility effect, divided attention, episodic memory, practice effects, learning context

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### Declaration of Academic Achievement

My supervisor, Dr. Scott Watter, and I designed the research conducted in this thesis. With the advice and guidance of Dr. Scott Watter, I conducted literature reviews, recruited participants and gathered data for both Experiments 1 and 2, and ran the data analyses. Dr. Scott Watter provided invaluable advice on the statistical methodology and composition of the paper. Sam Miljak, Rebecca Gallant, and Esther Manoian, all members of the Cognitive Science Laboratory, assisted with data collection for this project. I was responsible for writing the manuscript, with editorial advice from Dr. Scott Watter, as well as from my committee members, Dr. Karin Humphreys and Dr. Judith Shedden.

## INTRODUCTION

People perform worse on dual tasks compared to single tasks. The psychological refractory period (PRP) refers to the slowing that occurs when stimuli for a simple reaction time task are presented at short time intervals (Telford, 1931). The PRP paradigm is commonly used to measure dual task interference: two simple tasks (Task 1 and Task 2) are completed close together in time, with varying stimulus onset asynchronies (SOAs). In this paradigm, participants are instructed to make a primary response (R1) to a primary stimulus (S1) and a secondary response (R2) to a secondary stimulus (S2), as quickly and accurately as they can. As the SOA between Task 1 and Task 2 decreases, Task 2 reaction time (RT2) increases significantly, while Task 1 reaction time (RT1) remains relatively constant (Pashler, 1984).

Welford (1952) proposed that this slowing was caused by a central processing bottleneck. Pashler (1984, 1992, 1994) went on to suggest that this central processing bottleneck acted specifically on the response selection stage. Response selection refers to the act of cognitively selecting a response, following the perception of the stimulus and preceding the production of a motor response (e.g. pressing a button). The response selection bottleneck (RSB) theory suggests that prebottleneck (perception) and postbottleneck (motor production) stages can undergo parallel processing, but the response selection stage is constrained by a bottleneck and can only select one response at a time. Thus, Task 2 response selection cannot start until Task 1 response selection is completed (Pashler, 1992).

### **Backward Compatibility Effects**

While the RSB theory has proven to be quite robust (Ruthruff, Johnston, Van Selst, & Remington, 2006; Van Selst, Ruthruff, & Johnston, 1999), recent findings suggest that Task 2 response information influences Task 1 processing through backward compatibility effects (BCEs; Ellenbogen & Meiran, 2008; Hommel, 1998; Hommel & Eglau, 2002; Lien & Proctor, 2000; Thomson, Danis & Watter, 2015; Watter & Logan, 2006), indicating some parallel operation of response computation processes of both tasks.

For example, Hommel (1998) found that compatibility between Task 1 and Task 2 responses (i.e. both tasks requiring the same left- or right-sided response) led to significantly faster Task 1 RTs. These backward compatibility effects suggest that some parallel processing occurs during Task 1 response selection, which allows Task 2 response information to prime Task 1 processing. BCEs are believed to act on Task 1 response selection and not later motor production stages because previous studies showed that BCE development was influenced by compatibility of abstract semantic category information between Task 1 and Task 2, rather than compatibility of manual response information (Thomson, Watter, & Finkelshtein, 2010; Watter & Logan, 2006). This brings the RSB model under question, since a strict bottleneck would not allow for such parallel processing to occur. Hommel (1998) made the distinction between response selection and “response activation” stages, where response information for Task 2 can be activated in parallel with Task 1, but response selection must occur serially. Making the distinction between automatic response activation and controlled response selection reconciles the RSB model with the existence of BCEs.

### **Working Memory Versus Episodic Memory Mechanisms of the BCE**

Hommel (1998) proposed two alternative models to explain BCE development: a transient-link model and a direct-link model. The transient-link model suggests that stimulus-response (S-R) rules for both tasks are held active in working memory (WM) during task performance. These active S-R mapping rules allow for Task 2 response information to influence Task 1 response selection, creating the BCE. On the other hand, the direct-link model suggests that even if only one set of S-R rules can be held active at a time, direct S-R associations are accumulated with experience, and these S-R associations allow for automatic activation of Task 2 response information that can influence Task 1 processing, and create BCEs.

The transient-link model and the direct-link model make several distinct and testable predictions. Hommel and Eglau (2002) tested these predictions in order to distinguish the cognitive processes involved in BCE development. First, the transient-link model claims that S-R rules are held in WM. According to the transient-link model, BCE development should be sensitive to increased WM-load, since increasing WM-load would interfere with S-R rule activation. Hommel and Eglau (2002) tested this by administering an additional digit-memory task on every trial of the dual task. They found that increasing WM-load did not significantly interfere with BCE development. In a similar vein of thought, they increased WM-load by increasing the number of S-R rules for Task 1. This also did not significantly impair BCE development, suggesting that increased WM-load does not interfere with BCE development. According to the transient-link model, the activated S-R rules that contribute to BCEs are transient, and can be changed promptly

according to changing task demands. However, the direct-link model predicts that S-R associations accumulate with experience, and will outlive the needs of the task. Hommel and Eglau (2002) tested this by observing whether BCEs persisted even when Task 2 was no longer carried out. Indeed, significant BCEs were observed even after participants were instructed to ignore Task 2 stimuli, supporting the predictions of the direct-link model. They also found that switching Task 2 S-R rule mappings halfway through the experiment interfered with BCE development and eliminated them. Overall, these findings suggested that BCEs are caused by direct S-R associations that are built up with practice, rather than transient S-R rules held in WM.

More recently, Ellenbogen and Meiran (2008) sought to replicate the effects of increasing WM-load by increasing the number of S-R rules for Task 1. They argued that the previous design was not taxing enough to interfere with BCE development. First, they replicated Hommel and Eglau's (2002) experiment, and found that BCE development was not affected. However, when they increased the number of Task 1 S-R rules from four to six, they found significant impairment of BCE development, providing support for the transient-link model.

Giammarco, Thomson, and Watter's (2016) Experiment 1 tested the predictions of transient-link and direct-link models by looking at how single-task practice of either Task 1 or Task 2 influenced subsequent BCE development in a dual-task paradigm. According to the transient-link model, practicing either Task 1 or Task 2 should enhance BCE development by freeing up WM capacity to instantiate Task 2 rules. Hommel and Eglau (2002) further differentiated the direct-link model into a traditional learning model and an

episodic memory model. A traditional learning model predicts that single-task practice of Task 2 would increase learning and automaticity of Task 2 S-R associations, which would facilitate BCE development. Single-task practice of Task 1 may also increase BCE development by indirectly increasing the capacity of resources that can be dedicated to learning Task 2. In contrast to the traditional learning account, the episodic memory model makes predictions that are sensitive to the context in which the S-R associations are experienced. This is because the episodic memory model claims that the BCE is caused by an accumulation of episodic traces of S-R associations over multiple trials. For instance, single-task practice of Task 2 may enhance BCE development in a subsequent dual task, but only if it is practiced in a similar context. If Task 2 is practiced in a different context, the difference in context may in fact interfere with BCE development.

In order to test these predictions, Giammarco et al. (2016) randomized participants into four groups: Practice-Both, Practice-T2, Practice-T1, and Practice-None. The Practice-Both group practiced both Task 1 and Task 2 as single tasks in interleaved blocks. The Practice-T2 group practiced Task 2 interleaved with a random, filler task. The Practice-T1 group practiced Task 1 interleaved with a random, filler task. The Practice-None group practiced two different filler tasks. Following the single-task practice phase, all groups encountered the same dual-task phase, using Task 1 and Task 2. Consistent with predictions based on the episodic memory model, Giammarco et al. (2016) found that the Practice-Both group had significantly stronger BCEs in comparison to the Practice-None group. The Practice-T1 group did not have a significantly different BCE from the Practice-None group, and the BCE developed as usual. However, the Practice-

T2 group showed impaired BCE development, and in fact did not develop significant BCEs for the duration of the experiment. These findings were striking and showed strong evidence for BCE development being episodically-mediated.

The purpose of the present study is to examine the contextual specificity of BCE development. We sought to replicate the findings of Giammarco et al. (2016), looking specifically at single-task practice of Task 2 in differing contexts. While it is evident that the context of prior Task 2 practice is important to subsequent BCE development, the fine-grained details of how context influences BCE development have yet to be determined. We predict that, consistent with the findings of Giammarco et al. (2016), practicing Task 2 in a context different from the dual-task setting (i.e. without Task 1) will significantly impair BCE development.

### **Experiment 1a**

Participants performed a single-task practice phase, followed by a dual-task phase, similar to the Practice-T2 condition of Experiment 1 from Giammarco et al. (2016).

#### **Method**

**Participants.** Thirty-five undergraduate students enrolled in psychology courses at McMaster University (26 females) participated in the experiment for partial course credit. This study was approved by McMaster's Research Ethics Board, and all participants gave written informed consent prior to the experiment.

**Apparatus and stimuli.** The experiment was programmed using Presentation software ([www.neurobs.com](http://www.neurobs.com)). Participants were seated approximately 60 cm from the

computer monitor, and their responses were collected using a standard keyboard and mouse.

The single-task practice trials consisted of one stimulus presented in the centre of a black screen. The height and width of each stimulus was approximately 1.25 degrees of visual angle. Two basic tasks were used, similar to those used by Giammarco et al. (2016). For the *shape* task (filler task), the stimuli were four different shapes (circle, pentagon, diamond, and star) presented in white in the centre of a black screen. For the *colour* task (dual-task Task 2), the stimuli were coloured squares presented in red, yellow, blue, or green.

The dual-task phase consisted of two stimuli presented in the centre of a black screen. The Task 1 stimulus was always presented above the Task 2 stimulus, with a vertical separation of approximately  $0.4^\circ$ . Presentation of Task 1 and Task 2 stimuli were separated by an SOA of 0 or 500 ms. Task 1 was a novel *number* task and Task 2 was the same *colour* task from the single-task practice. Task 1 stimuli consisted of numbers 1 to 4 and 6 to 9, displayed in white, subtending  $1^\circ$  in height and  $0.8^\circ$  in width. Task 2 stimuli were the same coloured squares used in the single-task trials.

**Procedure.** *Single task.* The single-task phase consisted of eight blocks of 32 trials, alternating between tasks every two blocks. Each new task began with a practice block of 16 trials that were not included in analysis. Participants were instructed to respond to each stimulus as quickly and as accurately as possible. Following each block, participants received feedback regarding their mean reaction time and accuracy. They were also given the opportunity to rest before moving on to the next block.



The first task was the *colour* task, which required participants to make colour judgements of filled square stimuli. Responses were made by pressing the ‘Z’ key for ‘warm’ colours (red and yellow) and the ‘/’ key for ‘cool’ colours (blue and green) on a standard keyboard. Participants were instructed to make responses using their left and right index fingers, respectively. Stimulus mapping for Task 2 was the same for all participants, and remained unchanged throughout the experiment. After two blocks of the *colour* task, participants were taught the *shape* task, where participants made one response if the shape was either a star or diamond and a different response if the shape was a circle or a pentagon. Responses were made using the mouse scroll wheel, as either a full scroll ‘up’ or a full scroll ‘down’. Stimulus mapping for the filler task was counterbalanced across individuals.

Each single-task trial lasted 4000 ms and began with a fixation display for 500 ms, which consisted of two rows of two white dashes centred on the screen, separated laterally by approximately  $1.1^\circ$ . After 500 ms, the fixation display was replaced by the stimulus for 1000 ms, followed by a blank screen for 1500 ms, before the start of the next trial.

*Dual task.* The dual-task phase began with a practice block of 16 trials that were not included in analysis. The dual-task phase was identical for all participants, and consisted of six blocks of 32 trials. Task 1 was the *number* task and Task 2 was the *colour* task, presented in a PRP dual-task paradigm. Participants were instructed to respond to each stimulus as quickly and as accurately as possible, prioritizing Task 1. Task 1 required participants to indicate whether a number stimulus was ‘high’ or ‘low’.

Responses were made using the 'Z' key and the '/' key, and response mapping for Task 1 was counterbalanced across individuals. Task 2 stimulus mapping remained consistent from the previous phase.

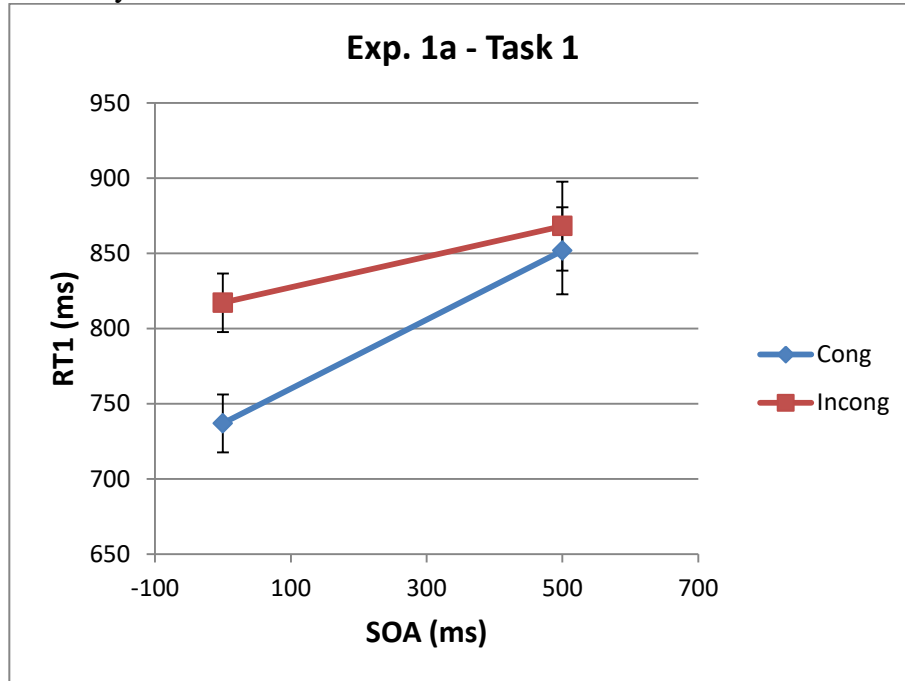
**Data Analysis.** Our analyses focused on data from the dual-task phase. Mean RT data were calculated based on trials with correct responses for both Task 1 and Task 2. Participants' data were excluded from analysis if overall accuracy was less than 70%, representing an approximate 85% per-task error rate. This resulted in the elimination of two participants' data, leaving 33 participants to be included in the analysis. Trials with response latencies of less than 200 ms on either Task 1 or Task 2, or greater than 2000 ms for Task 1 or 2500 ms for Task 2 were excluded from analysis.

Analysis of RT data focused on the development of backward compatibility effects, measured as response compatibility effects on Task 1 RT at 0 ms SOA. Similar to Giammarco et al. (2016), we excluded the first 38 trials (one-fifth of dual-task trials) from analysis in order to remove early high-variability trials that could be biased to not show BCEs. We then divided the rest of the dual-task trials into halves, to test for BCE development.

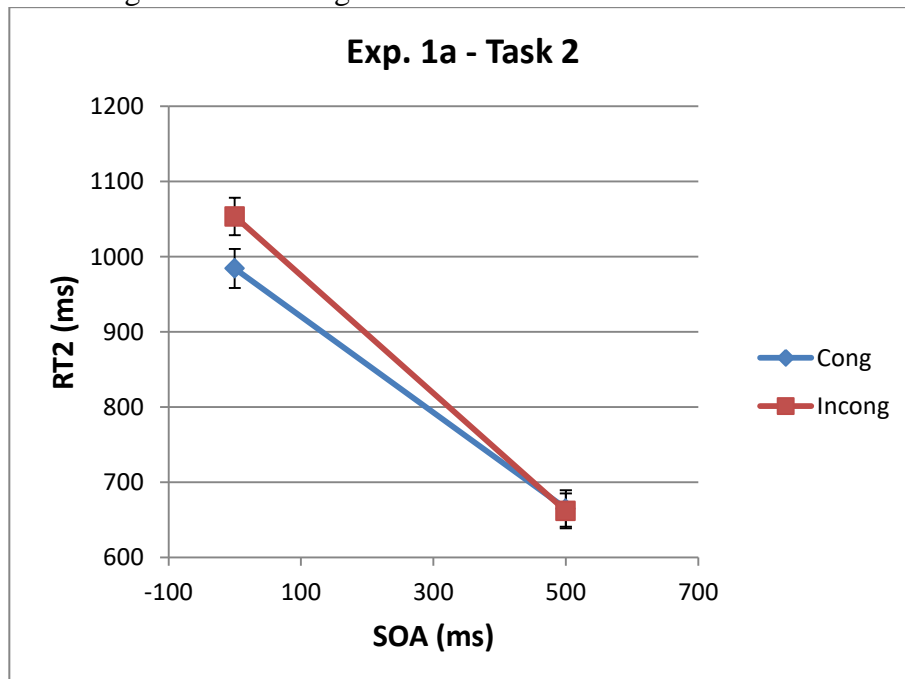
## **Results and Discussion**

Mean reaction times from the dual-task phase are presented in Figures 1a and 1b for Task 1 and Task 2, respectively, according to response congruency. Typical PRP effects were observed, with RT1 remaining relatively stable across SOAs while RT2 increased at smaller SOAs.

**Figure 1a.** Task 1 reaction time (RT1) data for Experiment 1a, divided by stimulus onset asynchrony (SOA) and response congruency. Data show typical PRP effects, with relatively flat RT1 across SOAs.

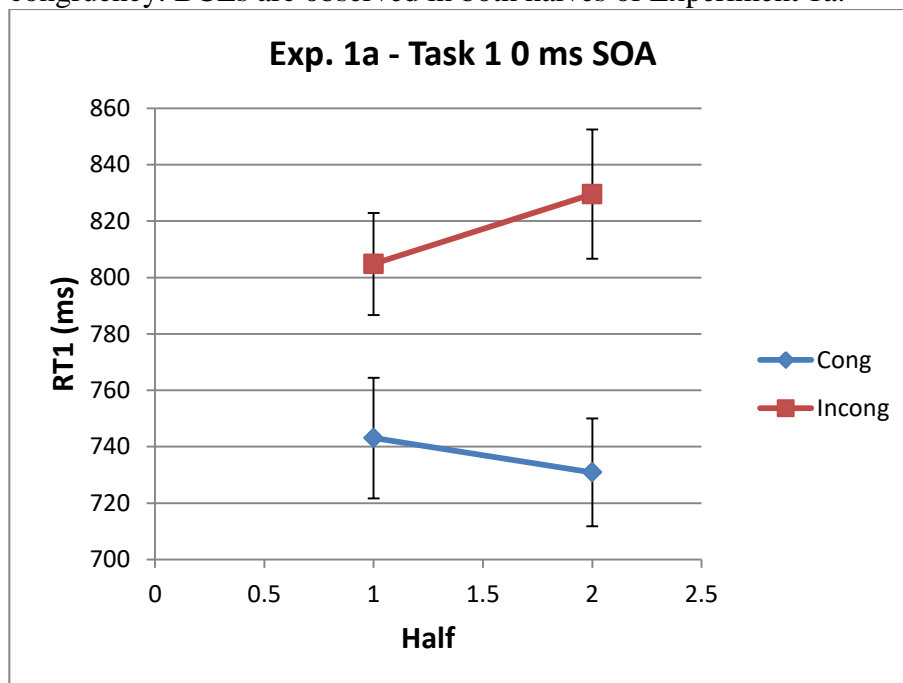


**Figure 1b.** Task 2 reaction time (RT2) data for Experiment 1a, divided by stimulus onset asynchrony (SOA) and response congruency. Data show typical PRP effects, with RT2 increasing with decreasing SOA.



For a better look at BCE development, we performed a 2 (half) x 2 (response congruency) repeated measures ANOVA on Task 1 0 ms SOA data. There was a main effect of response congruency on reaction time, demonstrating backward compatibility effects in Task 1 performance,  $F(1,33) = 31.511, p < .001$ . There was no main effect of half or interaction between half and response congruency,  $F_s < 1.4$ , indicating that the BCE developed in the first half and did not change significantly in amplitude from the first half to the second half. A graphical depiction of this is shown in Figure 2.

**Figure 2.** RT1 for 0 ms SOA data over experimental halves, divided by response congruency. BCEs are observed in both halves of Experiment 1a.



Overall, these findings suggest that contextual differences of prior Task 2 single-task practice did not interfere with BCE development. Unlike our predictions, prior single-task practice of Task 2 in the context of a random, filler task still increased learning and automaticity of Task 2 S-R associations, which facilitated early BCE

development from the first half of the dual-task phase. Our results did not coincide with the findings of Giammarco et al. (2016), where we saw Task 2 practice have contextually-sensitive effects on subsequent BCE development.

One limitation of Experiment 1a was the lack of counterbalancing in the single-task practice phase. While the single-task practice phase was counterbalanced in Giammarco et al. (2016), all participants in Experiment 1a began by learning Task 2 first and then learning the filler task. We addressed this in Experiment 1b, where a new group of participants were taught the filler task first before being introduced to Task 2 in the single-task practice phase. The purpose of Experiment 1b was to account for potential order effects in Experiment 1a and to confirm our findings.

### **Experiment 1b**

The purpose of Experiment 1b was to counterbalance the single-task practice phase of Experiment 1a and control for potential order effects.

#### **Method**

**Participants.** Forty undergraduate students enrolled in psychology courses at McMaster University (22 females) participated in the experiment for partial course credit. This study was approved by McMaster's Research Ethics Board, and all participants gave written informed consent prior to the experiment.

**Apparatus and stimuli.** Stimuli and apparatus used were identical with those used in Experiment 1a.

**Procedure.** *Single task.* Experiment 1b was identical to Experiment 1a, but counterbalanced the order of single task presentation. Participants were required to

complete the *shape* task first (filler task), followed by the *colour* task (Task 2). All other procedures and instructions were kept consistent with Experiment 1a.

*Dual task.* The dual-task phase was identical to Experiment 1a.

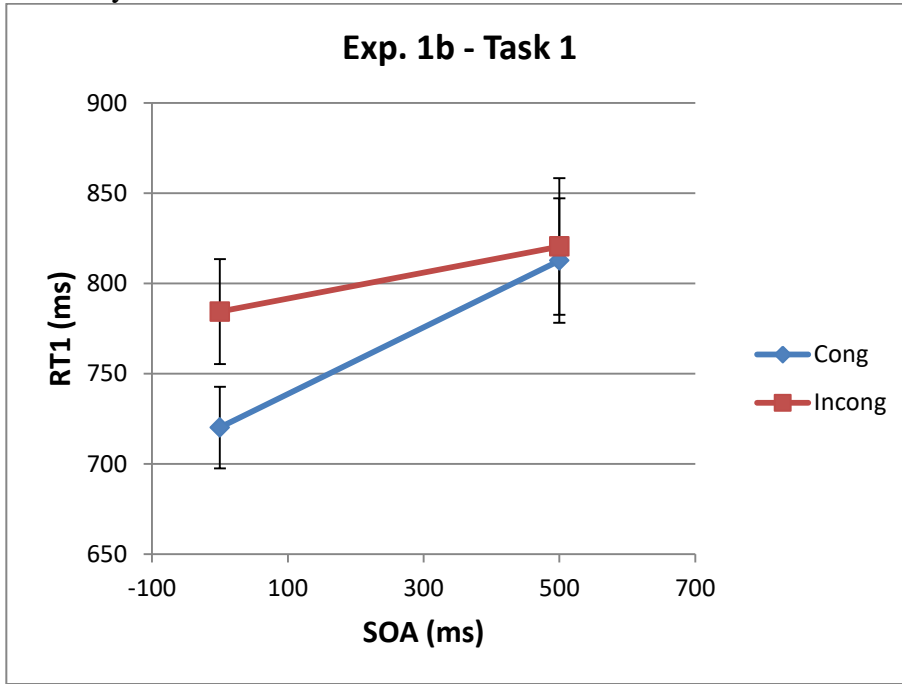
**Data Analysis.** Like in Experiment 1a, our analyses focused on data from the dual-task phase. Mean RT data were calculated based on trials with correct responses for both Task 1 and Task 2. Participants' data were excluded from analysis if accuracy was less than 70%, representing an approximate 85% per-task error rate. This resulted in the elimination of one participant's data, leaving 39 participants to be included in the analysis. Trials with response latencies of less than 200 ms on either Task 1 or Task 2, or greater than 2000 ms for Task 1 or 2500 ms for Task 2 were excluded from analysis.

Analysis of RT data focused on the development of backward compatibility effects, measured as response compatibility effects on Task 1 RT at 0 ms SOA. Like in Experiment 1a, we excluded the first dual-task block of 38 trials from analysis to minimize noise from high-variability trials. The remaining dual-task data were analyzed in experimental halves.

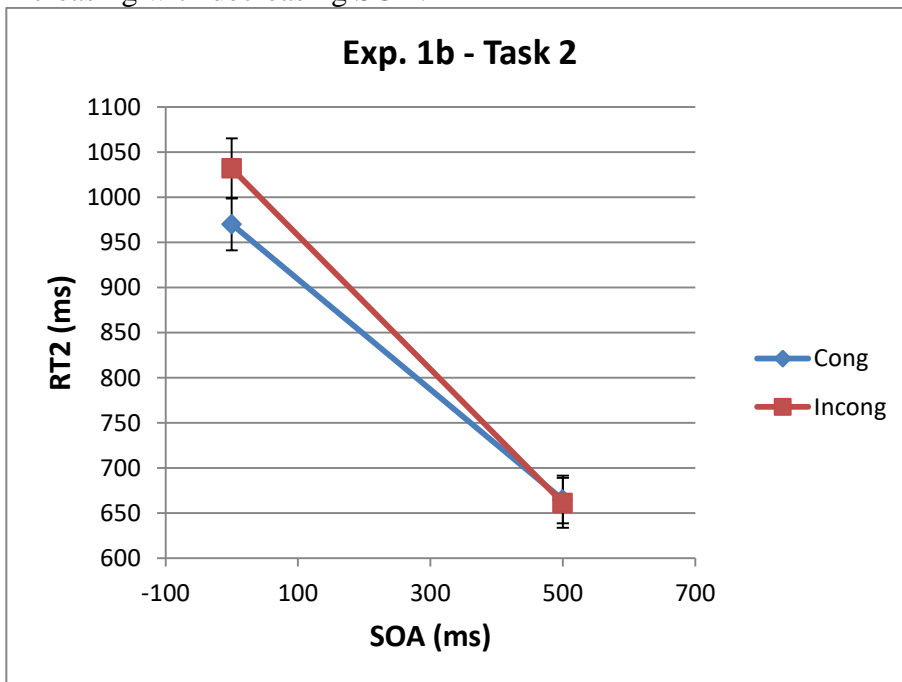
## **Results and Discussion**

Mean reaction times are presented in Figure 3a and 3b for Task 1 and Task 2, respectively, according to response congruency. Typical PRP effects were observed, with RT1 remaining relatively stable across SOAs while RT2 increased at smaller SOAs.

**Figure 3a.** Task 1 reaction time (RT1) data for Experiment 1b, divided by stimulus onset asynchrony (SOA) and response congruency. Data show typical PRP effects, with relatively flat RT1 across SOAs.

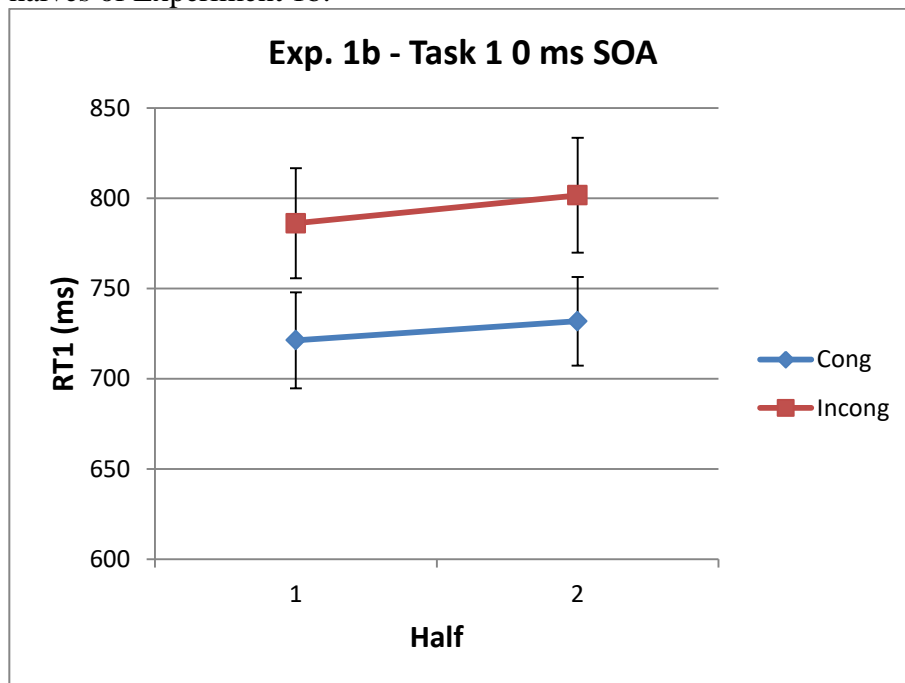


**Figure 3b.** Task 2 reaction time (RT2) data for Experiment 1b, divided by stimulus onset asynchrony (SOA) and response congruency. Data show typical PRP effects, with RT2 increasing with decreasing SOA.



For a better look at BCE development, we performed a 2 (half) x 2 (response congruency) repeated measures ANOVA on Task 1 0 ms SOA data. There was a main effect of response congruency on reaction time, demonstrating backward compatibility effects in Task 1 performance,  $F(1,38) = 20.954, p < .001$ . There was a marginal main effect of half on reaction time, suggesting that participants' reaction times improved with practice,  $F(1,28) = 3.644, p = .064$ . However, there was no interaction between half and response congruency,  $F < 0.7$ , indicating that the BCE developed in the first half and did not change significantly in amplitude from the first half to the second half. A graphical depiction of this is shown in Figure 4.

**Figure 4.** RT1 for 0 ms SOA data over experimental halves. BCEs are observed in both halves of Experiment 1b.



Overall, these findings confirmed our initial findings from Experiment 1a – contextual differences of prior single-task practice of Task 2 did not interfere with BCE



development, evident in the strong main effect of congruency in both first and second halves of the dual-task phase.

Our findings show that Task 2 single-task practice, even when performed in the context of learning a random, filler task, produces sufficient automaticity and learning of Task 2 S-R associations to facilitate BCE development in a subsequent dual-task. Unlike in Giammarco et al. (2016), where they found contextually-sensitive disruption of BCE development, the results of Experiment 1a and 1b suggest that prior Task 2 practice facilitate BCE development, regardless of the learning context.

In order to reconcile these findings, we conducted an exact replication of the Practice-T2 condition from Giammarco et al. (2016). This was to rule out any methodological differences that could have contributed to the disparate effects of Task 2 single-task practice on subsequent BCE development.

## **Experiment 2**

Experiment 1a and Experiment 1b sought to explore the effect of single-task practice of Task 2 in the context of a filler task on subsequent dual-task BCE development. In contrast to the observations of Giammarco et al. (2016), we found significant BCE development within the first half of the dual task, in spite of the different learning context.

These divergent findings prompted us to replicate the Practice-T2 condition from Experiment 1 of the Giammarco et al. (2016) study, to see if we could replicate the “selective context-sensitive disruption” of BCEs that they had observed. Replicating the disruption of BCE development would suggest that there was a key methodological

difference creating these divergent results. For instance, the context in which Task 2 was practiced may not have been sufficiently “different” enough to cause disruption in Experiments 1a and 1b. In contrast, an inability to replicate the findings of Giammarco et al. (2016) would suggest that the context of Task 2 learning may not play as big of a role as Task 2 practice itself. This would weaken support for the episodic memory model of the BCE, and lend further support to the traditional learning account of BCE development.

Experiment 2 was an exact replication of the Practice-T2 condition from Experiment 1 of Giammarco et al. (2016). By replicating their experiment exactly, we sought to confirm the context-sensitive effects of prior Task 2 learning on BCE development, and to identify potential contextual elements that could contribute to greater disruption of BCE development.

## **Method**

**Participants.** Thirty-nine undergraduate students enrolled in psychology courses at McMaster University (29 females) participated in the experiment for partial course credit. This study was approved by McMaster’s Research Ethics Board, and all participants gave written informed consent prior to the experiment.

**Apparatus and stimuli.** The experiment was programmed using Presentation software. Participants were seated approximately 60 cm from the computer monitor, and their responses were collected using a standard keyboard and a thumb joystick of a gamepad.

The single-task practice trials consisted of one stimulus presented in the centre of a black screen. The height and width of each stimulus was approximately 1.25 degrees of

visual angle. Two basic tasks were used, identical with those used for Practice-T2 condition in Experiment 1 of Giammarco et al. (2016). For the *case* task (filler task), the stimuli were four different letters from the English alphabet (A, E, G, and R) presented in white in the centre of a black screen. The letters were presented either in uppercase or lowercase Helvetica font. For the *colour* task (dual-task Task 2), the stimuli were coloured squares presented in orange, yellow, blue, or purple.

The dual-task phase consisted of two stimuli presented in the centre of a black screen. The Task 1 stimulus was always presented above the Task 2 stimulus, with a vertical separation of approximately 1.5 degrees of visual angle. Presentation of Task 1 and Task 2 stimuli were separated by an SOA of 0, 200, or 800 ms. Task 1 was a novel *shape* task and Task 2 was the same *colour* task from the single-task practice. Task 1 stimuli were four different shapes (circle, pentagon, diamond, and star) presented in white in the centre of a black screen. The height and width of each shape was approximately 1.25 degrees of visual angle. Task 2 stimuli were the same coloured squares used in the single-task trials.

**Procedure.** *Single task.* The single-task phase consisted of eight blocks of 32 trials, alternating between single tasks every two blocks in a counterbalanced order. Participants were instructed to respond to each stimulus as quickly and as accurately as possible. Following each block, participants received feedback regarding their mean reaction time and accuracy. They were also given the opportunity to rest before moving on to the next block.

In the *case* task, participants judged whether the letter stimulus was uppercase or lowercase. Each trial began with a letter displayed in white in the centre of the screen, next to a red square “cursor” (approx. 1 degree of visual angle) that moved with the joystick of a gamepad. The display also included a horizontal line presented 6.5 degrees of visual angle above and below the letter stimulus. Participants were instructed to move the joystick with their left thumb to push the cursor above the top line if the letter was uppercase, and pull the cursor below the bottom line if the letter was lowercase. Participants then pushed a button on the gamepad with their right thumb to submit their response and continue on to the next trial.

In the *colour* task, participants were required to make colour judgements of filled square stimuli as either ‘warm’ (orange and yellow) or ‘cool’ colours (blue and green). Trials began with a fixation display consisting of two white dashes centred on the screen for 500 ms. After 500 ms, the fixation display was replaced by the stimulus for 1000 ms, followed by a blank screen for 1500 ms, before the start of the next trial. Responses were made by pressing the 1 or 2 key on the number pad of a standard computer keyboard using the index or middle finger of their right hand. Response mapping was counterbalanced across individuals.

*Dual task.* The dual-task phase began with a practice block of 16 trials that were not included in analysis, and 192 experimental trials, divided into six blocks of 32 trials. Task 1 was the *shape* task and Task 2 was the *colour* task, presented in a PRP dual-task paradigm. Participants were instructed to respond to each stimulus as quickly and as accurately as possible, prioritizing Task 1. Responses were made using the 1 and 2 key on

the number pad of a standard keyboard with their right hand. Response mapping was counterbalanced across tasks, and Task 2 response mapping remained consistent from the single-task phase.

**Data Analysis.** Our analyses focused on data from the dual-task phase. Mean RT data were calculated based on trials with correct responses for both Task 1 and Task 2. Participants' data were excluded from analysis if overall accuracy was less than 70%, representing an approximate 85% per-task error rate. This resulted in the elimination of two participants' data, leaving 37 participants to be included in the analysis. Trials with response latencies of less than 200 ms on either Task 1 or Task 2, or greater than 2000 ms for Task 1 or 2500 ms for Task 2 were excluded from analysis.

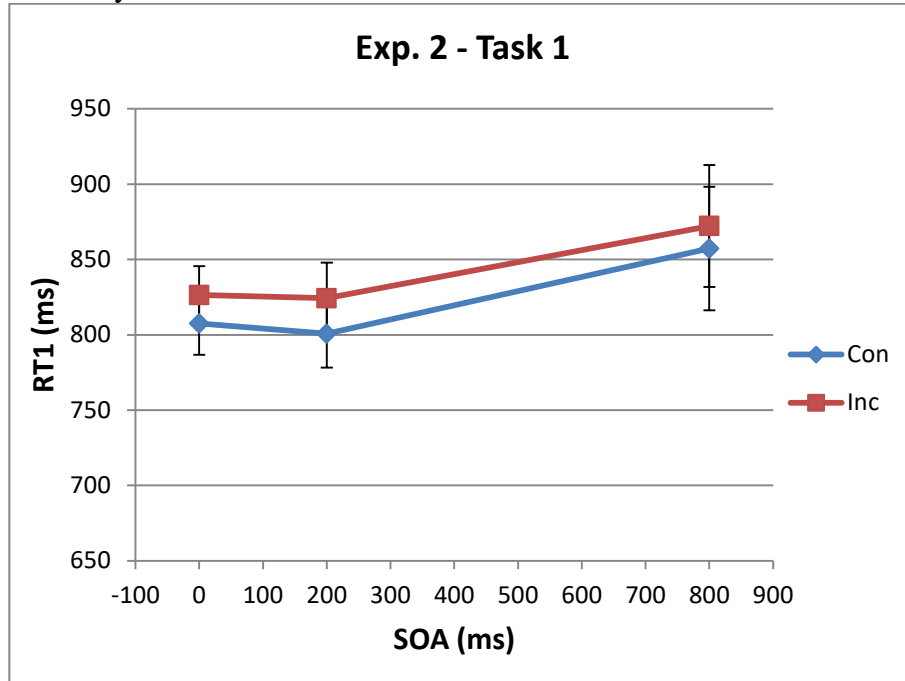
Analysis of RT data focused on the development of backward compatibility effects, measured as response compatibility effects on Task 1 RT at 0 ms SOA.

Again, we excluded the first dual-task block of 38 trials from analysis. We took this conservative approach to minimize noise that could bias our findings of any differences in BCE development.

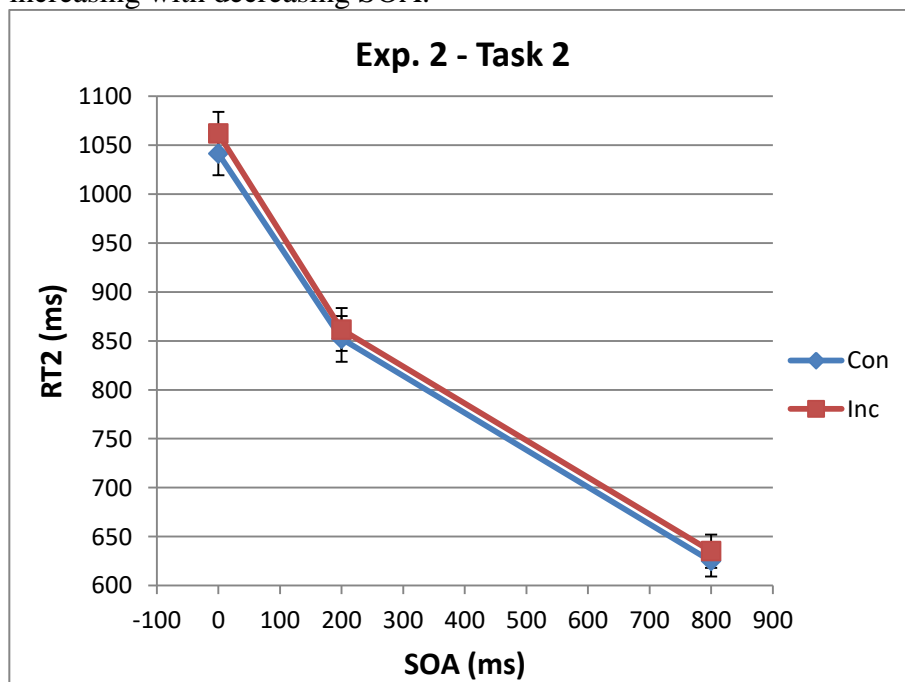
## **Results and Discussion**

Mean reaction times are presented in Figure 5a and 5b for Task 1 and Task 2, respectively, according to response congruency. Typical PRP effects were observed, with RT1 remaining relatively stable across SOAs while RT2 increased at smaller SOAs.

**Figure 5a.** Task 1 reaction time (RT1) data for Experiment 2, divided by stimulus onset asynchrony (SOA) and response congruency. Data show typical PRP effects, with relatively flat RT1 across SOAs.

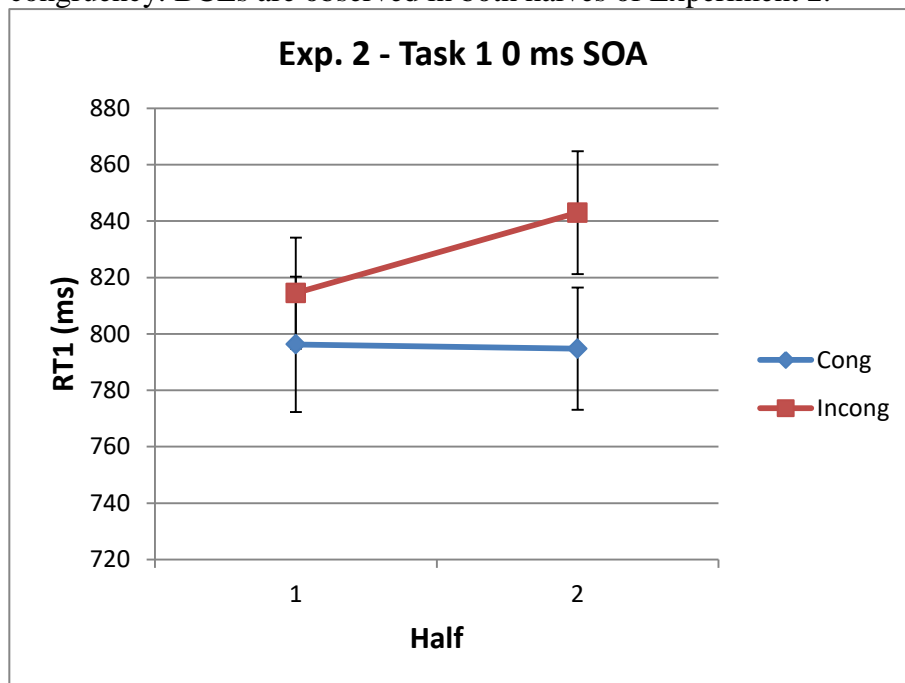


**Figure 5b.** Task 2 reaction time (RT2) data for Experiment 2, divided by stimulus onset asynchrony (SOA) and response congruency. Data show typical PRP effects, with RT2 increasing with decreasing SOA.



For a better look at BCE development, we performed a 2 (half) x 2 (response congruency) repeated measures ANOVA on Task 1 0 ms SOA data. There was a main effect of response congruency on reaction time, demonstrating backward compatibility effects in Task 1 performance,  $F(1,36) = 8.161, p = .007$ . There was a no significant effect of half or interaction between half and response congruency,  $F_s < 1.9 p > .1$ , indicating that the BCE amplitude did not change from the first half to the second half. A graphical depiction of this is shown in Figure 6.

**Figure 6.** RT1 for 0 ms SOA data over experimental halves, divided by response congruency. BCEs are observed in both halves of Experiment 2.



**Interresponse interval analyses.** We then assessed our 0 ms SOA Task 1 RT data, looking for participants with a disproportionate number of trials with short interresponse intervals (IRIs). A very short IRI suggests that participants may be grouping Task 1 and Task 2 responses together. In these cases, the BCE cannot be used as a reliable priming measure, since compatibility effects may be a product of deliberate

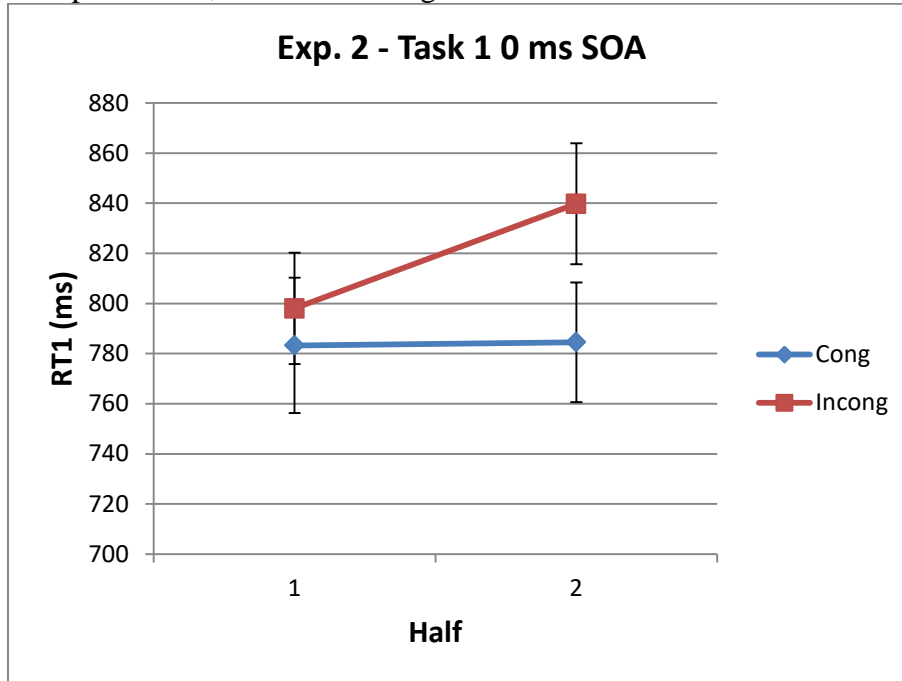
consideration of both tasks before responding rather than a measure of parallel response activation.

In order to account for possible response grouping effects in our results, we excluded data of participants who had more than 50% trials with IRIs shorter than 150 ms in the first half of Experiment 2. This resulted in the elimination of seven participants' data, leaving 30 participants to be included in the analysis.

We then performed another 2 (half) x 2 (response congruency) repeated measures ANOVA on Task 1 0 ms SOA data. There was a main effect of response congruency on reaction time, demonstrating backward compatibility effects in Task 1 performance,  $F(1,29) = 6.263, p = .018$ . There was a main effect of half,  $F(1,29) = 4.571, p = .041$ , suggesting that overall RT improved with practice. There was also a marginal interaction between half and response congruency,  $F(1,29) = 3.322, p = .079$ , indicating that the BCE amplitude showed marginal increase from the first half to the second half. A graphical depiction of our modified RT1 data at 0 ms SOA is shown in Figure 7.



**Figure 7.** Post-IRI analysis data of Experiment 2, showing RT1 at 0 ms SOA over experimental halves and response congruency. The BCE is nonsignificant in the first half of Experiment 2, and becomes significant in the second half.



Subsequent paired samples *t* tests showed that compatibility effects were nonsignificant in the first half,  $t(29) = 0.802, p = .429$ , but were significant in the second half,  $t(29) = 3.193, p = .003$ .

Although these results are not an identical replication of the results of Giammarco et al. (2016), the fact that the BCE did not develop in the first half despite prior single-task practice of Task 2 suggests that context-specific learning did occur. While the absolute time-course may vary from individual to individual, our results clearly show that practicing Task 2 in a different context did not potentiate BCE development.

## GENERAL DISCUSSION

The purpose of the present study was to test how single-task practice of Task 2 in the context of a novel task would influence subsequent dual-task BCE development.

Giammarco et al. (2016) found that practicing Task 2 in the context of the novel task extinguished BCE development in both first and second halves of the dual task, while practicing Task 2 in the context of Task 1 led to significant BCE development in the first half of the dual task. We sought to replicate this contextually-sensitive interference using different tasks, and assess the implications of our findings on the episodic memory model of automatic translation.

The results of Experiment 1a showed rapid BCE development following single-task practice of Task 2 interleaved with a novel mouse-scroll task. Experiment 1b accounted for potential order effects by counterbalancing the single-task practice phase of Experiment 1a. The results of Experiment 1b replicated the findings of Experiment 1a, showing significant BCEs from the first half of the dual task. In other words, there was no contextually-sensitive interference of BCE development. Rather, practicing Task 2 appeared to promote BCE development, in spite of the difference in context.

In Experiment 2, we conducted an exact replication of the Practice-T2 condition from Experiment 1 of Giammarco et al. (2016). Our results showed a conceptual replication of the findings from Giammarco et al. (2016) – there was no significant BCE development in the first half of the dual-task phase. This pattern of BCE development is comparable to those of the Practice-None and Practice-T1 conditions from Giammarco et al. (2016). Although our results did not show extinguished BCEs in both halves of the dual-task as in the original Practice-T2 condition, disruption of BCE development in the first half of the dual-task suggests that single-task practice of Task 2 in a different context did not cause sufficient learning and automaticity of Task 2 S-R associations to drive

immediate BCE development. Despite practicing Task 2 for a prolonged period of time, the BCE developed at a rate that was comparable to participants who had no prior practice of Task 2. This is consistent with the delayed task learning evident in Giammarco et al. (2016); the Task 2 S-R associations that were acquired during single-task practice were not immediately useful in the dual-task. These context-sensitive effects provide support for the episodic memory model of BCE development. The weaker disruption of the BCE in the current study may be explained by individual differences in rates of learning and building automaticity of these S-R associations. Further analyses should be done to rule out potential confounding effects of response grouping. As we saw in Experiment 2, individuals who group their responses together can manufacture what look like BCEs, and excluding such individuals may significantly alter overall compatibility effects.

Overall, our findings in Experiments 1a and 1b may be interpreted in several ways. A key difference between Experiment 1 and Experiment 2 was the response modality of the filler task. The filler task of Experiment 1 required participants to scroll the mouse wheel up or down using only their right middle finger. In contrast, the filler task of Experiment 2 used a joystick on a gamepad and required participants to push and hold the joystick up or down with their left thumb and then push a button with their right thumb. The more complex response for the filler task of Experiment 2, requiring two discrete actions (using both hands) rather than one, may have created a more “different” context for Task 2 single-task practice than the simple up-down scrolling response in Experiment 1. Having a more complex filler task to contextualize Task 2 S-R rules may have

strengthened encoding and subsequent recall of episodic Task 2 S-R associations, creating more interference in BCE development for Experiment 2 than Experiment 1.

On the other hand, based on Hommel's (2007) general event file framework, partial repetition of a stimulus and/or response feature leads to worse performance than a complete repetition or a complete alternation. It may be that there was a greater partial mismatch of response features in Experiment 2 than in Experiment 1, which contributed to disruption of Task 2 learning. The filler task and Task 2 shared some response features in Experiment 2: both required a button-press in the response. The filler task of Experiment 1, which required the up-down scrolling response, shared no response features with Task 2. It is possible that the filler task in Experiment 1 was not similar enough to Task 2 to create adequate interference in Task 2 learning via this partial mismatch in stimulus or response features.

Giammarco et al. (2016) suggested that having a high WM load Task 1 could disrupt acquisition of Task 2 S-R automaticity which is required for BCE production. We extended this idea to the acquisition of single-task S-R automaticity as well. The filler task in Experiment 1 was a shape task that categorized shapes rather arbitrarily (stars and diamonds versus circles and pentagons), while the filler task in Experiment 2 was a letter task that required differentiation between upper- and lower-case letters. Given that the categorization of upper- and lower-case letters is a familiar and well-established concept for most people, attaining S-R automaticity for the letter task would have been much easier than for the shape task. Shape categorization is less familiar and more arbitrary, so the filler task in Experiment 1 may have required more effortful and controlled processing.

This may have slowed and even prevented the acquisition of filler task S-R automaticity. In other words, the “context” of Task 2 may not have been sufficiently encoded in Experiment 1, which would explain the lack of interference and the immediate appearance of BCEs in the subsequent dual-task.

While our approach was sufficient for the purpose of identifying the presence and absence of BCEs, the precise measurement of the timecourse of BCE development was difficult, due to individual differences in rates of learning. In order to get a clearer and more complete picture of BCE development, future studies should take a more discriminatory approach, keeping in mind the potential effects of task difficulty and WM-load on creating the Task 2 context.

### **Conclusion**

Overall, our findings provide a conceptual replication of the context-sensitive disruption of BCE development observed by Giammarco et al. (2016). Prolonged single-task practice of Task 2 did not potentiate BCE development, due to a difference in context. Our divergent findings in Experiments 1a and 1b suggest that the Task 2 learning context may be characterized at a featural level, and warrants further investigation of differences in response features.

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