Isolating a Mediated Route for Response Congruency Effects in Task Switching

Darryl W. Schneider
Purdue University

Response congruency effects in task switching reflect worse performance for incongruent targets associated with different responses across tasks than for congruent targets associated with the same response. In the present study, the author investigated whether the effects can be produced solely by a mediated route for response selection, whereby targets are categorized with respect to both tasks, as opposed to a nonmediated route, whereby target–response instances from past experience are retrieved directly from long-term memory. The mediated route was isolated in 3 experiments by having subjects perform semantic categorization tasks on targets that were never repeated, thereby making the nonmediated route nonfunctional. Robust response congruency effects were observed for both response time and error rate in all experiments, indicating that the mediated route is sufficient to produce such effects by itself. The results imply that subjects engaged in dual-task processing despite no requirement to do so, raising questions about the modeling of response selection in task-switching situations.

Keywords: task switching, response congruency, dual-task processing, categorization

The human cognitive system is remarkable in its ability to deal with ambiguity in task-switching situations. On any given trial in a task-switching experiment, ambiguity could exist in determining which of two or more tasks to perform, identifying the relevant attribute of a multivalent stimulus, and selecting an appropriate response from a set of alternatives. Despite this uncertainty, people are capable of quick and accurate task-switching performance, rousing interest as to how the cognitive system accomplishes this feat (for reviews, see Kiesel et al., 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010). The purpose of the present study was to isolate a mechanism by which response selection occurs in task-switching situations.

I focused on ambiguity in response selection arising from a manipulation of response congruency, which refers to whether a target stimulus requires the same response (congruent) or different responses (incongruent) for two tasks. For example, consider two semantic categorization tasks (living–nonliving and small–large judgments) for the referents of target words (e.g., ant, coin, elephant, sofa). The living–nonliving task involves categorizing a target as living or nonliving (e.g., ant and elephant are living; coin and sofa are nonliving). The small–large task involves categorizing a target as small or large relative to the size of a basketball (e.g., ant and coin are small; elephant and sofa are large). Ambiguity exists in response selection when the categories for the two tasks are mapped to the same pair of response keys. If the living and small categories are mapped to a left response key and the nonliving and large categories are mapped to a right response key, then congruent targets are either living and small (e.g., ant) or nonliving and large (e.g., sofa), and incongruent targets are either living and large (e.g., elephant) or nonliving and small (e.g., coin). A common finding in task-switching experiments involving these types of category–response mappings is a response congruency effect: response time (RT) is longer and error rate is higher for incongruent targets than for congruent targets (e.g., Brown, Reynolds, & Braver, 2007; Kiesel, Wendt, & Peters, 2007; Meiran & Kessler, 2008; Monsell, Sumner, & Waters, 2003; Schneider & Logan, 2009, 2014; Sudevan & Taylor, 1987).

Two main explanations for the response congruency effect have been proposed in the task-switching literature: a mediated route and a nonmediated route (e.g., Kiesel et al., 2007; Meiran & Kessler, 2008; Schneider & Logan, 2009, 2014; Yamaguchi & Proctor, 2011; see also Pashler & Baylis, 1991). The mediated route involves first determining which category is associated with a target (e.g., elephant is living), then determining the response associated with that category (e.g., living requires a left keypress response). The route is mediated because the path from target to response involves the intermediate step of forming a categorical representation of the target (Schneider & Logan, 2010), possibly in conjunction with categorization of a task cue (Arrington, Logan, & Oberauer, 2007). A response congruency effect can be produced if the speed and accuracy of response selection depend on how responses are activated via category–response mappings. Response selection should be facilitated by having both target categories activate the same response, as would occur with a congruent target, but impaired by having both target categories activate different responses, as would occur with an incongruent target. A task cue would be needed to guide response selection for an incongruent target when there is conflicting response activation. An important aspect of this account is that performance involves dual-task processing, which is defined in the present context as categorizing...
the target with respect to both tasks even when only one task is cued.

The nonmediated route involves determining which response is associated with a target via direct retrieval from long-term memory (e.g., remembering that ant requires a left keypress response regardless of the cued task). The route is nonmediated because the path from target to response bypasses the intermediate step of categorization. Instances of target–response associations can form in long-term memory from frequent experience with a set of targets, and then those instances can be retrieved when targets are repeated (Logan, 1988, 2002). A response congruency effect can be produced if direct retrieval is faster and more accurate than categorization. Response selection should be facilitated when direct retrieval yields a unique response, as would occur with a congruent target, but impaired when direct retrieval yields conflicting responses, as would occur with an incongruent target. Target categorization and a task cue would be needed to guide response selection for an incongruent target when the nonmediated route fails to yield a unique response. An important aspect of this account is that performance does not involve processing for either task, because the target directly retrieves a response from long-term memory regardless of which task is cued.

Previous studies have provided evidence implicating either the mediated route or the nonmediated route as the source of the response congruency effect, although in some cases the results were equivocal. Meiran and Kessler (2008) conducted experiments in which targets and responses were either easy or difficult to categorize based on familiar or abstract spatial codes, respectively. When categorization was easy, response congruency effects were observed for RT and error rate, as would be expected if the mediated route were used for response selection, although such effects are also consistent with the nonmediated route. When categorization was difficult, response congruency effects were present for error rate but absent for RT. The absence of an effect on RT suggests the mediated route was nonfunctional for the difficult categorization tasks, but the presence of an effect on error rate suggests otherwise. The nonmediated route could explain the error-rate effect, given that the experiments involved four repeated targets for which multiple target–response instances could be stored in and retrieved from long-term memory. However, it is unclear why the nonmediated route would produce a response congruency effect on error rate but not on RT, unless the two behavioral measures reflect different cognitive processes (as suggested by Meiran & Kessler, 2008).

Schneider and Logan (2014) reported experiments in which subjects performed the living–nonliving and small–large tasks described earlier, but the order of cue and target presentation was manipulated (cue before target or target before cue). Response congruency effects were observed for RT and error rate for both stimulus orders, but a key finding was that early responding occurred for congruent targets with target–cue order on some trials. Responding to the target before the cue presentation was possible only if subjects either categorized the target with respect to both tasks via the mediated route or retrieved a response to the target from long-term memory via the nonmediated route. Schneider and Logan modeled their data with a simulated version of the mediated route, but they acknowledged the possible involvement of the nonmediated route in performance.

Kiesel et al. (2007) reported an experiment in which subjects repeated and switched between parity (odd or even) and magnitude (smaller or larger than 5) tasks for single-digit targets. Half of the targets occurred with both tasks, whereas the other half occurred with only one task. Larger response congruency effects on RT and error rate were obtained for the targets that occurred with both tasks than for those that occurred with only one task. Kiesel and colleagues interpreted these target-specific effects as evidence for the nonmediated route, but they can also be interpreted as evidence for the mediated route because its role in response selection may be strengthened for targets that are frequently categorized with respect to both tasks. Moreover, response congruency effects were still observed for the targets that occurred with only one task, implicating the mediated route (for a related finding, see Koch & Allport, 2006).

In a subsequent study, Wendt and Kiesel (2008) reported an experiment involving parity and magnitude tasks in which the category–response mappings for the parity task were reversed halfway through the experiment. In addition, all targets occurred with the magnitude task but only half of the targets occurred with the parity task. For the targets that were exclusive to the magnitude task, the mapping reversal for the parity task led to a gradual disappearance of the response congruency effect on RT but a quick inversion of the effect on error rate. For the targets that were common to both tasks, the mapping reversal for the parity task immediately inverted the response congruency effects (defined with respect to the original mappings) for both RT and error rate. A mapping reversal for selected targets led to a similar inversion of the response congruency effect for error rate in a study by Waszak, Pfister, and Kiesel (2013). These inversions of the response congruency effect indicate that targets were directly linked to specific responses, implicating the nonmediated route.

Yamaguchi and Proctor (2011) obtained evidence that further supports the nonmediated route. They conducted an experiment in which color and shape tasks were either intermixed randomly within blocks (mixed-task blocks) or alternated across separate blocks (pure-task blocks). Response congruency effects were observed for RT and error rate in both block conditions, which is notable for the pure-task blocks because no trial-to-trial task switching occurred (for a related finding, see Yehene, Meiran, & Soroker, 2005). Overall RTs were shortest in the pure-task blocks, leading Yamaguchi and Proctor to infer that subjects focused exclusively on the single relevant task in those blocks, implying that the mediated route did not produce the observed response congruency effects. Given that the four possible targets were repeated often, target–response instances could have formed in long-term memory during both pure- and mixed-task blocks and been retrieved via the nonmediated route.

Some evidence supporting the mediated route comes from Liefgooge and colleagues (Liefgooge, De Houwer, & Wenke, 2013; Liefgooge, Wenke, & De Houwer, 2012; but see Waszak, Wenke, & Brass, 2008), who conducted experiments in which subjects were instructed about a pair of target–response mappings (e.g., “if N, press left; if Q, press right”) for an inducer task at the start of each run of trials. Before receiving a probe for the inducer task at the end of the run, subjects performed multiple trials of a different diagnostic task (judging the orientation of a letter) involving the same targets (e.g., N and Q). Different targets were used across runs, which meant that the inducer task always...
changed but the diagnostic task remained the same. Response congruency effects were observed for RT and error rate in diagnostic task performance, even though the inducer task had yet to be performed. Liefooghe and colleagues interpreted their results as evidence that the instructed but unpracticed target–response mappings of the inducer task were automatically applied during the diagnostic task, implicating the mediated route. Related results were reported by Wenke, Gaschler, and Nattkemper (2007), and analogous results have been found for the flanker compatibility effect by Cohen-Kdoshay and Meiran (2007, 2009).

Reisenauer and Dreisbach (2013) reported experiments in which subjects were presented with compound word–picture stimuli (e.g., the word leg superimposed on a picture of a spinning top), where the words were targets and the pictures were distractors for performing a single task (judging whether each word referred to a moving or a nonmoving object). Some of the pictures illustrated target word referents, and others did not (target-related and -unrelated distractors, respectively). Response congruency effects were observed for both types of distractors, such that performance was better when the task-appropriate responses for target and distractor matched than when they mismatched. Given that the target-unrelated distractors were never presented as targets, the response congruency effect in that condition could not have reflected access to target–response associations in long-term memory via the nonmediated route. Instead, it must have arisen from automatic categorization of distractors, implicating the mediated route.

In summary, past research has provided support for both the mediated and the nonmediated routes as mechanisms for producing response congruency effects. The present study was motivated by the observation that most task-switching experiments are designed in a way that favors the nonmediated route because they involve a small set of frequently repeated targets. As discussed earlier, every time a response is selected for a target, an instance of that target–response association can be stored in long-term memory. Upon repetition of a target, those instances can be retrieved to quickly select a response. With a small target set, instance-based retrieval has the opportunity to dominate response selection, especially for congruent targets. Under these circumstances, any response congruency effects may primarily reflect the nonmediated route.

The goal of the present study was to determine whether the mediated route can produce response congruency effects in situations where it is impossible for the nonmediated route to affect response selection. To achieve this goal, I conducted three task-switching experiments in which the living–nonliving and small–large tasks described earlier were performed on a large set of target words that were never repeated. Without target repetition, a target cannot retrieve an associated response from long-term memory, because there are no target–response instances available from past experience. Consequently, the nonmediated route becomes nonfunctional and cannot produce response congruency effects. If response congruency effects are observed with nonrepeated targets, then the only possible explanation is that the mediated route produced the effects.

The idea of making the nonmediated route nonfunctional was also studied by Liefooghe and colleagues (Liefooghe et al., 2012, 2013). As noted earlier, their approach involved instructing subjects about specific target–response mappings but not practicing them, with this inducer task changing across runs of trials. My approach differed from theirs in four important respects. First, subjects received no instructions about specific target–response mappings in my experiments; instead, they were instructed about category–response mappings and had to categorize each target to determine the appropriate response. Second, subjects practiced both tasks in my experiments instead of performing one task while holding the instructions for an unpracticed task in memory. Third, both tasks were intermixed in blocks of trials in two of my experiments, enabling analyses of task transition effects (differences between task switches and task repetitions). Fourth, both tasks remained unchanged throughout my experiments. These features of my experiments are common to many task-switching experiments, potentially allowing the findings to be generalized more broadly than those of past studies.

**Experiment 1**

Experiment 1 involved the explicit task-cuing procedure (Sudevan & Taylor, 1987; for an overview, see Meiran, 2014), in which a cue indicates the relevant task to perform on the target during each trial. The cues were living–nonliving and small–large for living–nonliving and small–large tasks, respectively, performed in random order on 320 target words that each appeared only once in the entire experiment. The question of interest was whether response congruency effects would be observed with nonrepeated targets, for which the nonmediated route is nonfunctional and the mediated route is the sole mechanism available for response selection.

**Method**

**Subjects.** Forty students from Purdue University participated for course credit. Data from four additional subjects were excluded for mean error rates exceeding a preset inclusion criterion of 20%. The sample size of 40 was determined by a power analysis using an effect-size estimate based on previous research. More specifically, I calculated the mean effect size (Cohen’s $d$) for the response congruency effect on RT in the 1:1 cue–task mapping conditions of Experiments 1–3 from Schneider and Logan (2011). The large effect size ($d = 1.17$) may reflect contributions to the response congruency effect from both mediated and nonmediated routes because those experiments involved a small set of repeated targets. Given that the present experiments involved a large set of nonrepeated targets that made the nonmediated route nonfunctional, I expected that a smaller effect size might be obtained. For simplicity, I assumed an effect size of $d = 0.59$, which is half of the value from Schneider and Logan’s study. Using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007), I determined that 40 subjects would provide statistical power of .95 to detect a response congruency effect of that size.

**Apparatus, tasks, stimuli, and responses.** The experiment was conducted with E-Prime (Version 2.0) software running on computers that displayed stimuli on monitors and registered responses from QWERTY keyboards. Stimuli were displayed in white 18-point Courier New font on a black background at a viewing distance of approximately 50 cm.

Two semantic categorization tasks were performed on the referents of target words. The living–nonliving task, which was cued...
by the words living–nonliving, involved pressing a key to indicate whether a target referred to something that was living or nonliving. The instructions defined a living thing as any kind of organism, animal, insect, tree, plant, flower, fruit, or vegetable. The small–large task, which was cued by the words small–large, involved pressing a key to indicate whether a target referred to something that was small or large relative to the size of a standard basketball.

Responses were made with the D and K keys on the keyboard, with same-task categories mapped to different keys (e.g., living and small categories mapped to the D key; nonliving and large categories mapped to the K key). The four possible sets of category–response mappings were counterbalanced across subjects. The left–right order of the category words composing the cues matched the left–right order of the response keys for each subject, thereby serving as a reminder of the category–response mappings (e.g., a subject with large and small categories mapped to the D and K keys, respectively, had large–small as a cue).

The category–response mappings defined the response congruency of the targets. For example, consider a subject with living and small categories mapped to the D key and nonliving and large categories mapped to the K key. Congruent targets would be living and small (e.g., ant) or nonliving and large (e.g., sofa), whereas incongruent targets would be living and large (e.g., elephant) or nonliving and small (e.g., coin). The target set consisted of 320 words compiled from various sources, with 80 words for each combination of the living/nonliving and small/large categories. Half of the targets were incongruent and the other half congruent for each subject. Due to the counterbalancing of category–response mappings, a given target was incongruent for half of the subjects and congruent for the other half. Targets were matched across categories on word length and word frequency. Mean word lengths were 5.8, 5.8, 5.9, and 6.1 letters for the living–small, living–large, nonliving–small, and nonliving–large category combinations, respectively. Mean word frequencies were 6.0, 6.2, 6.2, and 6.2 occurrences per million for the living–small, living–large, nonliving–small, and nonliving–large category combinations, respectively. Separate 2 (living/ nonliving) × 2 (small/large) repeated-measures analyses of variance (ANOVARs) on word length and word frequency revealed no significant effects (all Fs < 1).}

Procedure. Subjects were seated at computers in individual testing rooms after providing informed consent for a study protocol approved by the Purdue University Institutional Review Board. Instructions were presented onscreen and read aloud by the experimenter.

The experiment was divided into eight blocks of 40 trials, with self-paced rest periods between blocks. Each trial began with two vertically arranged fixation crosses presented in the center of the screen. After 500 ms, the top fixation cross was replaced by a task cue. After 1,000 ms, the bottom fixation cross was replaced by a target. Cue and target remained onscreen until the subject responded, and then the next trial commenced after a blank screen was shown for 500 ms. Thus, the cue–target and response–cue intervals were each 1,000 ms for all trials.

Subjects were instructed to respond quickly and accurately when performing the cued task on the target. There were no overt reminders of the noncued task or its category–response mappings on any trial. Subjects were informed that the cue would precede the target, and they were encouraged to prepare in advance for the appropriate categorization. Cue and target were chosen randomly on each trial, subject to the constraint that each task was performed equally often on targets from all four category combinations in every block. As a result, incongruent and congruent targets were presented equally often for each task in every block. In addition, task switches (e.g., the living–nonliving task followed by the small–large task) and task repetitions (e.g., the living–nonliving task followed by the living–nonliving task) occurred randomly across trials. Each target was used only once in the entire experiment, and subjects were informed that the targets would never be repeated.

Results

The first block was considered practice and excluded from all analyses except for the analyses of practice effects. The first trial of each subsequent block was excluded because it lacked an immediately preceding trial for classifying it as a task switch or task repetition. Trials with RTs more than three standard deviations above the mean in each condition for a given subject were excluded (2.0% of trials were RT outliers). Error trials were excluded from the RT analyses.

Mean correct RTs are presented as a function of response congruency and task transition in Figure 1A. The data were submitted to a repeated-measures ANOVA with those variables as factors. Incongruent trials (1,223 ms) were slower than congruent trials (1,182 ms), resulting in a significant main effect of response congruency, $F(1, 39) = 14.58, MSE = 4,759.86, p < .001, \eta^2_p = .27$. The response congruency effect of 42 ms had a 95% confidence interval [20, 64] that did not include zero and an effect size ($d = 0.60$) that was close to the estimate ($d = 0.59$) used in the power analysis to determine sample size. Task switches (1,252 ms) were slower than task repetitions (1,153 ms), resulting in a significant main effect of task transition, $F(1, 39) = 56.55, MSE = 6,905.51, p < .001, \eta^2_p = .59$. The interaction between response congruency and task transition was nonsignificant, $F(1, 39) = 0.03, MSE = 6,449.46, p = .87, \eta^2_p < .01$.

Additional analyses were conducted to determine the stability of the response congruency effect as a function of practice and across the RT distribution. To analyze practice effects, the data were partitioned by halves of the experiment and submitted to a repeated-measures ANOVA with response congruency and half as factors. RT did not change much from the first half (1,230 ms) to the second half (1,198 ms), resulting in a nonsignificant main effect of half, $F(1, 39) = 1.43, MSE = 28,763.23, p = .24, \eta^2_p = .04$. The response congruency effect increased from 4 ms in the first half to 69 ms in the second half, resulting in a significant interaction between response congruency and half, $F(1, 39) = 9.76, MSE = 4,297.92, p = .003, \eta^2_p = .20$.

To analyze RT distributions, cumulative distribution functions (CDFs) were computed for incongruent and congruent trials separately for each subject, using quantiles from .1 to .9 in increments of .1. Each quantile indicates the proportion of trials with RTs shorter than the quantile RT, with the .5 quantile being the median RT. Individual-subject CDFs were averaged across corresponding quantiles to produce the group CDFs displayed in Figure 2. The data were submitted to a repeated-measures ANOVA with response congruency and quantile as factors. The response congruency effect did not vary systematically across quantiles, resulting

This document is copyrighted by the American Psychological Association or one of its allied publishers. This article is intended solely for the personal use of the individual user and is not to be disseminated broadly.
Incongruent trials (8.8%) had more errors than did congruent trials and for a repeated-measures ANOVA with those variables as factors. Error rate did not change much from the first half (7.5%) to the second half (6.7%), resulting in a nonsignificant main effect of half, $F(1, 39) = 1.89$, $MSE = 11.57, p = .18, \eta_p^2 = .05$. The response congruency effect decreased from 5.4% in the first half to 2.9% in the second half, resulting in a significant interaction between response congruency and half, $F(1, 39) = 7.84, MSE = 7.97, p = .008, \eta_p^2 = .17$. Note that this practice effect is in the opposite direction of that for RT.

Discussion

The key findings from Experiment 1 were response congruency effects for RT and error rate. These effects cannot be explained by direct retrieval of responses via the nonmediated route because no targets were repeated during the experiment and, as a result, no target–response instances could be accessed from long-term memory. Instead, the effects represent unequivocal evidence that response selection involved categorization via the mediated route, a mechanism that was sufficient to produce response congruency effects by itself.

For the mediated route to produce response congruency effects, it was necessary to process the target to the point of response selection for both tasks. This dual-task processing occurred despite only one task being cued on each trial and a 1,000-ms cue–target interval providing ample opportunity to prepare exclusively for the relevant task. Subjects could have categorized each target solely with respect to the cued task, but their behavior suggests otherwise, raising the question of why they engaged in dual-task processing. A possible reason was examined in the next experiment.

Experiment 2

The dual-task processing that occurred in Experiment 1 could be due to the random cuing of tasks across trials. Not knowing which task to expect on the next trial, subjects may have kept the information needed to perform both tasks available in working memory at all times. When switching tasks, having information already accessible for the now-relevant task might have facilitated performance, even if it meant retaining information for the now-irrelevant task. Thus, the dual-task processing that enabled the mediated route to produce response congruency effects in Experiment 1 might not occur if trial-to-trial task uncertainty is removed.

To eliminate task uncertainty, Experiment 2 involved the alternating-runs procedure (Rogers & Monsell, 1995), in which tasks are cued in a predictable order. Following the typical procedure, tasks alternated after runs of two trials (e.g., living–dying).

Figure 1. Mean correct response time and mean error rate as a function of response congruency and task transition in Experiment 1. Error bars represent 95% confidence intervals (Masson & Loftus, 2003).

in a nonsignificant interaction between response congruency and quantile, $F(8, 312) = 1.24, MSE = 3.097.01, p = .27, \eta_p^2 = .03$.

Mean error rates are presented as a function of response congruency and task transition in Figure 1B. The data were submitted to a repeated-measures ANOVA with those variables as factors. Incongruent trials (8.8%) had more errors than did congruent trials (5.2%), resulting in a significant main effect of response congruency, $F(1, 39) = 12.79, MSE = 39.92, p = .001, \eta_p^2 = .25$. The response congruency effect of 3.6% had a 95% confidence interval [1.5%, 5.6%] that did not include zero and an effect size ($d = 0.56$) similar to what was observed for RT. Task switches (7.6%) had more errors than did task repetitions (6.3%), resulting in a significant main effect of task transition, $F(1, 39) = 10.15, MSE = 6.84, p = .003, \eta_p^2 = .21$. The interaction between response congruency and task transition was significant, $F(1, 39) = 11.26, MSE = 11.51, p = .002, \eta_p^2 = .22$, and reflected a larger response congruency effect for task switches (5.4%) than for task repetitions (1.8%).

To analyze practice effects, the data were partitioned by halves of the experiment and submitted to a repeated-measures ANOVA with response congruency and half as factors. Error rate did not change much from the first half (7.5%) to the second half (6.7%), and for a repeated-measures ANOVA with those variables as factors. Error rate did not change much from the first half (7.5%) to the second half (6.7%), resulting in a nonsignificant main effect of half, $F(1, 39) = 1.89$, $MSE = 11.57, p = .18, \eta_p^2 = .05$. The response congruency effect decreased from 5.4% in the first half to 2.9% in the second half, resulting in a significant interaction between response congruency and half, $F(1, 39) = 7.84, MSE = 7.97, p = .008, \eta_p^2 = .17$. Note that this practice effect is in the opposite direction of that for RT.

EXP. 2: Two experiments were conducted. In the first experiment, the data were submitted to a repeated-measures ANOVA with response congruency and half as factors. Error rate did not change much from the first half (7.5%) to the second half (6.7%), resulting in a nonsignificant main effect of half, $F(1, 39) = 1.89$, $MSE = 11.57, p = .18, \eta_p^2 = .05$. The response congruency effect decreased from 5.4% in the first half to 2.9% in the second half, resulting in a significant interaction between response congruency and half, $F(1, 39) = 7.84, MSE = 7.97, p = .008, \eta_p^2 = .17$. Note that this practice effect is in the opposite direction of that for RT.

To analyze practice effects, the data were partitioned by halves of the experiment and submitted to a repeated-measures ANOVA with response congruency and half as factors. Error rate did not change much from the first half (7.5%) to the second half (6.7%), resulting in a nonsignificant main effect of half, $F(1, 39) = 1.89$, $MSE = 11.57, p = .18, \eta_p^2 = .05$. The response congruency effect decreased from 5.4% in the first half to 2.9% in the second half, resulting in a significant interaction between response congruency and half, $F(1, 39) = 7.84, MSE = 7.97, p = .008, \eta_p^2 = .17$. Note that this practice effect is in the opposite direction of that for RT.
nonliving, living–nonliving, small–large, small–large). Subjects were informed of the predictable task sequence and encouraged to use it to prepare for the relevant task on each trial. The method was otherwise identical to that of Experiment 1. In particular, no targets were repeated, explicit task cues were still presented, and the response–cue and cue–target intervals each remained at 1,000 ms. Given the absence of task uncertainty, subjects could prepare exclusively for the relevant task during the 2,000-ms response–target interval. If dual-task processing occurs despite these procedural features, then response congruency effects should still be observed.

Method

Subjects. Forty students from Purdue University participated for course credit. None of them had participated in Experiment 1. Data from two additional subjects were excluded for mean error rates exceeding 20%.

Apparatus, tasks, stimuli, and responses. Identical to those in Experiment 1.

Procedure. The procedure was identical to that of Experiment 1, except for the following changes. In Experiment 1, tasks occurred randomly across trials; in Experiment 2, tasks alternated every two trials (e.g., living–nonliving, living–nonliving, small–large, small–large). For half of the subjects, all blocks started with the living–nonliving task; for the other half, it was the small–large task. Subjects were informed that the tasks would occur in a predictable, repeating order across trials and they were encouraged to use that predictability to prepare in advance for the appropriate categorization. A task cue was still presented on every trial and the trial timing remained unchanged from Experiment 1.

Results

Data trimming was identical to that of Experiment 1 (2.0% of trials were RT outliers), and the data were analyzed in the same manner.

Mean correct RTs are presented as a function of response congruency and task transition in Figure 3A. The data were submitted to a repeated-measures ANOVA with those variables as factors. Incongruent trials (1,222 ms) were slower than congruent trials (1,180 ms), resulting in a significant main effect of response congruency, $F(1, 39) = 7.16, MSE = 9,662.18, p = .01, \eta^2_p = .16$. The response congruency effect of 42 ms had a 95% confidence interval [10, 73] that did not include zero and an effect size ($d = 0.42$) that was slightly smaller than that observed for RT in Experiment 1. Task switches (1,257 ms) were slower than task repetitions (1,145 ms), resulting in a significant main effect of task transition, $F(1, 39) = 45.38, MSE = 11,048.92, p < .001, \eta^2_p = .54$. The interaction between response congruency and task transition was nonsignificant, $F(1, 39) = 2.26, MSE = 5,527.85, p = .14, \eta^2_p = .06$.

Additional analyses were conducted to determine the stability of the response congruency effect as a function of practice and across
the RT distribution. To analyze practice effects, the data were partitioned by halves of the experiment and submitted to a repeated-measures ANOVA with response congruency and half as factors. RT did not change much from the first half (1,184 ms) to the second half (1,232 ms), resulting in a nonsignificant main effect of half, $F(1, 39) = 1.79$, $MSE = 52,338.37$, $p = .19$, $\eta^2_p = .04$. The response congruency effect increased from 15 ms in the first half to 61 ms in the second half, resulting in a nearly significant interaction between response congruency and half, $F(1, 39) = 4.04$, $MSE = 5,212.82$, $p = .051$, $\eta^2_p = .09$.

To analyze RT distributions, group CDFs were computed for incongruent and congruent trials and are displayed in Figure 4. The data were submitted to a repeated-measures ANOVA with response congruency and quantile as factors. The response congruency effect did not vary systematically across quantiles, resulting in a nonsignificant interaction between response congruency and quantile, $F(8, 312) = 0.16$, $MSE = 11,106.77$, $p > .99$, $\eta^2_p < .01$.

Mean error rates are presented as a function of response congruency and task transition in Figure 3B. The data were submitted to a repeated-measures ANOVA with those variables as factors. Incongruent trials (6.4%) had more errors than did congruent trials (2.8%), resulting in a significant main effect of response congruency, $F(1, 39) = 19.94$, $MSE = 25.94$, $p < .001$, $\eta^2_p = .34$. The response congruency effect of 3.6% had a 95% confidence interval [2.0%, 5.2%] that did not include zero and an effect size ($d = 0.71$) that was slightly larger than that observed for errors in Experiment 1. Task switches (5.3%) had more errors than did task repetitions (3.9%), resulting in a significant main effect of task transition, $F(1, 39) = 9.06$, $MSE = 8.06$, $p = .005$, $\eta^2_p = .19$. The interaction between response congruency and task transition was nonsignificant, $F(1, 39) = 1.50$, $MSE = 8.16$, $p = .23$, $\eta^2_p = .04$.

To analyze practice effects, the data were partitioned by halves of the experiment and submitted to a repeated-measures ANOVA with response congruency and half as factors. Error rate did not change much from the first half (4.3%) to the second half (4.8%), resulting in a nonsignificant main effect of half, $F(1, 39) = 0.94$, $MSE = 9.15$, $p = .34$, $\eta^2_p = .02$. The response congruency effect was 3.4% in both halves, resulting in a nonsignificant interaction between response congruency and half, $F(1, 39) = 0.02$, $MSE = 4.68$, $p = .91$, $\eta^2 = .01$.

Discussion

The key findings from Experiment 2 were response congruency effects for RT and error rate, replicating Experiment 1. These effects cannot be explained by the nonmediated route, given that no targets were repeated, but they are fully consistent with the mediated route. Moreover, the dual-task processing underlying the mediated route occurred despite the relevant task being predictable from trial to trial, suggesting that task uncertainty was not responsible for the results of Experiment 1. An alternative reason for why subjects engaged in dual-task processing was examined in the next experiment.

Experiment 3

The dual-task processing that occurred in Experiments 1 and 2 could be due to anticipation of task switching across trials. It was suggested earlier that subjects may keep the information needed to perform both tasks available in working memory at all times because they do not know which task to expect on the next trial. The results of Experiment 2 ruled out this idea, but not the alternative possibility that subjects hold information for both tasks in working memory because they know they will switch tasks soon. Regardless of whether a task switch is predictable, having information readily accessible when switching tasks might facilitate performance. Thus, the dual-task processing that enabled the mediated route to produce response congruency effects in Experiments 1 and 2 might not occur if trial-to-trial task switching is removed.

To eliminate task switching at the trial level, Experiment 3 involved an alternating-blocks procedure similar to the pure-task block condition of Yamaguchi and Proctor (2011). Subjects performed the same task on all trials within each block, but switched tasks from one block to the next. They were informed of the block structure and encouraged to prepare solely for the relevant task in each block. The method was otherwise identical to that of Experiments 1 and 2, including nonrepetition of targets, presentation of explicit task cues, and long response–cue and cue–target intervals. Given the absence of task switching within blocks, subjects could prepare exclusively for the relevant task. If dual-task processing occurs despite these procedural features, then response congruency effects should still be observed.

Method

Subjects. Forty students from Purdue University participated for course credit. None of them had participated in Experiments 1 or 2. Data from three additional subjects were excluded for mean error rates exceeding 20%.

Apparatus, tasks, stimuli, and responses. Identical to those of Experiments 1 and 2.

Procedure. The procedure was identical to that of Experiments 1 and 2, except for the following changes. In Experiments 1 and 2, both tasks occurred within each block of trials; in Experiment 3, a single task occurred within each block and the relevant
task alternated across blocks (e.g., living–nonliving task in Block 1, small–large task in Block 2, living–nonliving task in Block 3). To have each task occur equally often every 40 trials (as in Experiments 1 and 2), block length in Experiment 3 was shortened from 40 to 20 trials, but the number of blocks was increased from eight to 16 to maintain the same total number of trials. For half of the subjects, the first block involved the living–nonliving task; for the other half, it was the small–large task. Subjects were informed that only one task would be relevant during each block, and, at the start of every block, an onscreen prompt indicated the relevant task for that entire block. Thus, subjects could prepare exclusively for the relevant task to be performed for the next 20 trials. The trial timing remained unchanged from Experiments 1 and 2.

Results

Data trimming was identical to that of Experiments 1 and 2 (2.0% of trials were RT outliers). The first two blocks—each of which involved a different task—were considered practice and excluded from all analyses except for the analyses of practice effects. Given the absence of task switching within blocks, task transition could not be included as a factor in any analyses.

Mean correct RTs for incongruent trials (909 ms) were longer than for congruent trials (876 ms), resulting in a significant effect of response congruency, F(1, 39) = 4.03, SE = 8.13, p < .001. The response congruency effect of 33 ms had a 95% confidence interval [16, 49] that did not include zero and an effect size (d = 0.64) that was larger than those observed for RT in Experiments 1 and 2.

Additional analyses were conducted to determine the stability of the response congruency effect as a function of practice and across the RT distribution. To analyze practice effects, the data were partitioned by halves of the experiment and submitted to a repeated-measures ANOVA with response congruency and half as factors. RT became longer from the first half (870 ms) to the second half (911 ms), resulting in a significant main effect of half, F(1, 39) = 7.28, MSE = 9,019.04, p = .01. The response congruency effect did not change much from the first half (29 ms) to the second half (32 ms), resulting in a nonsignificant interaction between response congruency and half, F(1, 39) = 0.05, MSE = 2,025.56, p = .82. The low variability in RT could focus exclusively on one task.

To analyze RT distributions, group CDFs were computed for incongruent and congruent trials and are displayed in Figure 5. The data were submitted to a repeated-measures ANOVA with response congruency and quantile as factors. The response congruency effect increased systematically from 4 ms at the .1 quantile to 69 ms at the .9 quantile, resulting in a significant interaction between response congruency and quantile, F(8, 312) = 5.63, MSE = 1,318.77, p < .001. The low variability in RT due to the absence of task switching within blocks may have increased the power to detect this effect, which may explain why such an effect was not found in the more variable RT data of Experiments 1 and 2.

Mean error rates for incongruent trials (8.4%) were higher than for congruent trials (4.5%), resulting in a significant effect of response congruency, n(39) = 5.66, SE = 0.70, p < .001. The response congruency effect of 3.9% had a 95% confidence interval [2.5%, 5.3%] that did not include zero and an effect size (d = 0.89) that was larger than those observed for errors in Experiments 1 and 2.

To analyze practice effects, the data were partitioned by halves of the experiment and submitted to a repeated-measures ANOVA with response congruency and half as factors. Error rate did not change much from the first half (6.7%) to the second half (6.4%), resulting in a nonsignificant main effect of half, F(1, 39) = 0.24, MSE = 9.55, p = .62. The response congruency error effect did not change much from the first half (3.5%) to the second half (4.0%), resulting in a nonsignificant interaction between response congruency and half, F(1, 39) = 0.28, MSE = 7.91, p = .60.

Discussion

The key findings from Experiment 3 were response congruency effects for RT and error rate, replicating Experiments 1 and 2. Experiment 3 also replicates the results from the pure-task block condition of Yamaguchi and Proctor (2011), but with nonrepeated targets instead of repeated targets. These effects cannot be explained by the nonmediated route, but they are fully consistent with the mediated route. In particular, they suggest that dual-task processing via the mediated route occurred in single-task blocks, even though there was no trial-to-trial task switching and subjects could focus exclusively on one task.

General Discussion

The purpose of the present study was to investigate the mechanisms underlying response congruency effects in task switching. According to the mediated route for response selection, response congruency effects arise when targets are categorized with respect to both tasks. According to the nonmediated route, the effects arise when target–response instances from past experience are retrieved directly from long-term memory. In three experiments, I isolated the mediated route by having subjects perform living–nonliving and small–large tasks on targets that were never repeated, thereby
making the nonmediated route nonfunctional. Experiment 1 involved random cuing of tasks with long response–cue and cue–target intervals. Experiment 2 removed trial-to-trial task uncertainty by having tasks occur in predictable, alternating runs. Experiment 3 removed trial-to-trial task switching by having tasks occur in alternating blocks. Robust response congruency effects were observed for both RT and error rate in all experiments, indicating that the mediated route is sufficient to produce such effects by itself.

The results of the present study complement and extend previous findings that implicated the mediated route as a source of response congruency effects. The finding of response congruency effects for targets that occurred with only one task (Kiesel et al., 2007; Koch & Allport, 2006) was replicated in the present study, which showed that such effects can be obtained even when targets are not repeated. The finding of response congruency effects associated with instructed but unpracticed target–response mappings (Lietooghe et al., 2012, 2013; Wenke et al., 2007; see also Cohen-Kdoshay & Meiran, 2007, 2009) was also replicated in the sense that none of the target–response mappings were tested in any of my experiments. Notably, the response congruency effects in the present study were observed in contexts where subjects practiced both tasks, which remained unchanged throughout each experiment and could be intermixed in blocks of trials. Moreover, the effects were demonstrated in variants of three common task-switching procedures: explicit task cuing, alternating runs, and pure-task blocks (in Experiments 1–3, respectively).

Besides indicating that the mediated route is sufficient to produce response congruency effects, the present study provides additional insight into the nature of its functioning. The analyses of practice effects indicated that the response congruency effect on RT tended to increase with practice (Experiments 1 and 2), suggesting that task experience led to faster categorization of novel targets and the response congruency of previous trials.3

It is notable that the response congruency effect was not modulated consistently by task transition, with the interaction between response congruency and task transition being significant only for error rate in Experiment 1. The fickleness of this interaction has also been observed in other studies (e.g., Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Monsell et al., 2003) and may reflect the functioning of the mediated route. As discussed earlier, response selection via the mediated route involves dual-task processing, defined in this context as categorizing the target with respect to both tasks even when only one task is cued. If this were not the case, then response congruency effects would not have been observed in the present study. Dual-task processing on some trials could blur the internal distinction between task switches and task repetitions, dampening any interaction between response congruency and task transition, as well as complicating the interpretation of task-switch costs.

Having established the existence of the mediated route, it is worthwhile exploring how this mode of response selection can be implemented in computational models of task switching. Dual-task processing via the mediated route can occur only if the cognitive system is set up to perform both the relevant and the irrelevant tasks on each trial. This is possible if there is an all-encompassing task set that enables concurrent processing for both tasks, consistent with Jersild’s (1927) early proposal that task switching might entail the formation of a comprehensive but somewhat inefficient task set. This possibility has been realized in some computational models of task switching (e.g., Gilbert & Shallice, 2002; Meiran, 2000; Schneider & Logan, 2005). For example, compound cue retrieval is an extant model that implements the mediated route and naturally produces response congruency effects (Logan & Schneider, 2010; Schneider & Logan, 2005, 2009, 2014). According to the model, responses are selected in task-switching situations by using the joint evidence provided by categorization of the cue and the target presented on each trial to drive a random-walk decision process (Nosofsky & Palmeri, 1997). When the categorical evidence from the target is mapped to a single response, as in the case of a congruent target, response selection by the model is faster and more accurate than when the evidence is mapped to different responses, as in the case of an incongruent target (for details, see Schneider & Logan, 2009, 2014). Consequently, the model demonstrates at a mechanistic level that the mediated route is sufficient for producing response congruency effects.

An outstanding issue is how the existence of the mediated route can be reconciled with evidence that implicates the nonmediated route in task-switching performance (Kiesel et al., 2007; Waszak et al., 2013; Wendt & Kiesel, 2008; Yamaguchi & Proctor, 2011). In contrast with the mediated route, which involves dual-task processing, the nonmediated route involves no processing for either task, because the target directly retrieves a response from long-term memory regardless of which task is cued. This is possible if associations between targets and responses are formed in memory and can be used to influence subsequent response selection. This possibility has been realized to a limited extent in computational models of task switching. For example, Altmann and Gray’s (2008) cognitive control model implements a variant of the nonmediated route that produces response congruency effects. According to the model, a target–response association can form for a congruent target because it leads consistently to the same response. When a congruent target is encountered repeatedly, it can directly prime its associated response, aiding memory retrieval to make response selection faster and more accurate. It is unclear how the associations are learned and whether any associative priming occurs for incongruent targets, but the model demonstrates at a

---

2 RT was generally longer for the small–large task than for the living–nonliving task. However, the only significant interaction between response congruency and task occurred for RT in Experiment 3, F(1, 39) = 4.57, MSE = 3.680.42, p = .04, η² = .11, reflecting a larger response congruency effect for the small–large task (49 ms) than for the living–nonliving task (8 ms).

3 The response congruency effect was modulated by the response congruency of previous trials only for error rate in Experiment 2, F(1, 39) = 4.86, MSE = 5.25, p = .03, η² = .11, where there was a larger response congruency effect when the previous trial was congruent (4.2%) versus incongruent (2.6%).
mechanistic level that the nonmediated route is also sufficient for producing response congruency effects under some circumstances.

A worthwhile objective for future research would be to determine how the mediated and the nonmediated routes could be integrated in the same model to accommodate the diverse findings in the literature. Following suggestions by Schneider and Logan (2014), the two routes could operate in parallel, with the response determined by whichever route finishes its processing first (Logan, 1988, 2002) or by combining the evidence accumulated from each route. Alternatively, the routes could operate alone or in series, with the cognitive system choosing which route to use on each trial and switching to the other route if the first one fails (Anderson & Lebiere, 1998). Given that many task-switching experiments involve categorization tasks and frequently repeated targets, it seems plausible for both the mediated and the nonmediated routes to contribute to response selection. The challenge from a modeling perspective would be to determine how to implement each route and select responses based on one or the other (or both). The challenge from an experimental perspective would be to determine how to empirically distinguish between the routes in situations where both might be involved in behavior. Meeting these challenges will likely result in a better understanding of response congruency effects in particular and task-switching performance in general.

References


Received March 19, 2014
Revision received June 10, 2014
Accepted June 13, 2014

E-Mail Notification of Your Latest Issue Online!

Would you like to know when the next issue of your favorite APA journal will be available online? This service is now available to you. Sign up at http://notify.apa.org/ and you will be notified by e-mail when issues of interest to you become available!