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Attentional Control of Response Selection in Task Switching

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Modulation of cognitive control was investigated by using a proportion congruent manipulation to change response congruency effects in task switching. In an experiment that involved cued switching between semantic categorization tasks, targets were either congruent or incongruent (mapped to the same or different responses across tasks, respectively), and the proportion of congruent targets was manipulated between subjects. Response congruency effects (worse performance for incongruent than for congruent targets) were observed, and they increased with proportion congruent for both response time and error rate. A sequential congruency effect (a smaller response congruency effect following an incongruent than a congruent trial) was observed for error rate, but only for task repetitions. The results suggested top-down control of attention rather than bottom-up control based on item-specific learning, because targets were never repeated during the experiment. Implications for understanding attentional control of response selection in conflict situations are discussed.

Keywords: task switching, response congruency, proportion congruent, attention, cognitive control

Cognitive control enables people to behave appropriately in ambiguous contexts that afford conflicting thoughts and actions (Logan, 1985; Monsell, 1996; Norman & Shallice, 1986). For example, in the Stroop task (Stroop, 1935; for a review, see MacLeod, 1991), cognitive control is involved in naming the ink color of a color word to a greater extent when ink color and word identity indicate different responses (an incongruent trial; e.g., the word *red* in blue ink) than when they indicate the same response (a congruent trial; e.g., the word *red* in red ink). As another example, in task-switching studies (for reviews, see Kiesel et al., 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010), cognitive control is thought to be involved to a greater extent when switching tasks (e.g., from word reading to color naming) than when repeating the same task. In each context, cognitive control helps to resolve the conflict between responses or tasks that gives rise to Stroop effects (worse color-naming performance on incongruent trials than on congruent trials) or switch costs (worse performance for task switches than for task repetitions), possibly by focusing attention on relevant features of the stimulus or task and filtering out irrelevant features. Identifying these behavioral effects of cognitive control and understanding the mechanisms by which control is implemented continue to be important goals in research on cognition. The purpose of the present study was to investigate the modulation of cognitive control by examining how a proportion congruent manipulation changes response congruency effects in task switching.

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Proportion Congruent Effects

The Stroop effect and other congruency effects indicate the involvement of cognitive control in resolving conflict, but manipulations that change those effects provide insight regarding how cognitive control can be modulated. One such manipulation is to vary the proportion of congruent trials in Stroop-like tasks, which results in larger congruency effects when trials are mostly congruent than when they are mostly incongruent (e.g., Kane & Engle, 2003; Lindsay & Jacoby, 1994; Logan, 1980; Logan & Zbrodoff, 1979; Logan, Zbrodoff, & Williamson, 1984; Lowe & Mitterer, 1982; for reviews, see Bugg, 2012; Bugg & Crump, 2012). An early account of this proportion congruent effect attributed it to top-down control over how attention is divided between relevant and irrelevant stimulus features (Logan, 1980; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982). When trials are mostly incongruent, attention can be allocated toward relevant features and away from irrelevant features to reduce interference from the latter, resulting in attenuated congruency effects. When trials are mostly congruent, more attention can be allocated toward irrelevant features because they support the same response as the relevant features, resulting in amplified congruency effects. By this account, varying the proportion of congruent trials modulates cognitive control by changing how attention is allocated to stimuli, thereby adjusting the weighting of relevant and irrelevant features in response selection to either decrease or increase congruency effects accordingly.

More recently, accounts of proportion congruent effects have shifted from top-down control of attention to bottom-up control based on item-specific learning. The impetus for the shift was evidence for a distinction between listwide proportion congruent effects (from manipulating proportion congruent across lists or blocks of trials) and item-specific proportion congruent effects (from manipulating proportion congruent for specific stimuli within a list or block of trials). For example, in experiments in which the listwide proportion congruent was 50%, Jacoby, Lindsay, and Hessels (2003) found larger congruency effects for specific stimuli that were mostly congruent than for stimuli that were mostly incongruent (see also Blais & Bunge, 2010; Bugg & Hutchison, 2013; Bugg, Jacoby, & Chanani, 2011; Bugg, Jacoby, & Toth, 2008). These item-specific proportion congruent effects cannot be explained in terms of top-down control of attention, because any global modulation of attention should affect all trials and not be restricted to specific stimuli. Instead, the effects seem to reflect bottom-up control of attention, whereby past experience leads to learning of whether a given stimulus is usually congruent or incongruent, and that information is retrieved from memory and used to modulate control of subsequent stimulus processing (Bugg & Crump, 2012; for an alternative account based on contingency learning, see Schmidt & Besner, 2008). Computational models based on conflict-modulated learning at the item level (Blais, Robidoux, Risko, & Besner, 2007; Verguts & Notebaert, 2008) can account for both item-specific and listwide proportion congruent effects because they are confounded in many experimental designs (i.e., manipulating proportion congruent for a list of trials typically involves manipulating proportion congruent for specific stimuli; for example designs, see Bugg, 2012).

The question of whether and when proportion congruent effects reflect top-down or bottom-up control of attention continues to be debated, with recent evidence indicating that both may be involved in some contexts (Bugg, 2014; Bugg & Chanani, 2011; Bugg, McDaniel, Scullin, & Braver, 2011; Hutchison, 2011). The present study is relevant to this debate because I investigated whether proportion congruent effects occur with a listwide proportion congruent manipulation under circumstances that preclude bottom-up control as an explanation of such effects. Instead of focusing on Stroop effects, I examined how response congruency effects in a task-switching context are influenced by a proportion congruent manipulation.

Response Congruency Effects

Similar to the Stroop effect, the response congruency effect in task switching arises from different features of a target stimulus being associated with the same response or different responses. The response congruency effect is often demonstrated in task-switching experiments involving two categorization tasks, such as living–nonliving and small–large judgments of the referents of target words (e.g., *frog*, *pebble*, *camel*, *stove*). The living–nonliving task involves categorizing a target as living (*frog* and *camel*) or nonliving (*pebble* and *stove*), whereas the small–large task involves categorizing a target as small (*frog* and *pebble*) or large (*camel* and *stove*) compared with the size of a reference object (e.g., a basketball). When the two tasks are intermixed across trials, switch costs are commonly observed, with task switches (e.g., the living–nonliving task followed by the small–large task) yielding worse performance than task repetitions (e.g., the small–large task followed by the small–large task; Arrington & Logan, 2004; Schneider, 2015; Schneider & Logan, 2007, 2015).

More relevant to the present context is what happens when task categories are mapped to overlapping responses—for example, the living and small categories being mapped to a left response key and the nonliving and large categories being mapped to a right response key. Under these circumstances, some targets are congruent because they are mapped to the same response across tasks (e.g., *frog* is living and small, requiring a left keypress response for both tasks), whereas other targets are incongruent because they are mapped to different responses across tasks (e.g., *camel* is living and large, requiring a left keypress response for the living–nonliving task but a right keypress response for the small–large task). The response congruency effect is the common finding that 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, 2014, 2015; Schneider & Logan, 2009, 2014, in press; Sudevan & Taylor, 1987).

Response congruency effects have been explained in terms of two routes for response selection: a mediated route involving categorization and a nonmediated route involving direct retrieval (Kiesel et al., 2007; Meiran & Kessler, 2008; Schneider, 2014, 2015; Schneider & Logan, 2009, 2014, in press; Yamaguchi & Proctor, 2011). The mediated route involves accessing semantic memory to determine the task-relevant categories associated with a target (e.g., *frog* is living and small), then activating the response(s) associated with those categories (e.g., living and small both require a left keypress response). Response selection is impaired for incongruent targets because their categories activate conflicting responses, whereas it is facilitated for congruent targets because their categories activate a unique response, with the result being a response congruency effect. The nonmediated route involves using the target to retrieve an associated response directly from long-term memory by accessing target–response instances accumulated from past experience (Logan, 1988, 2002). Response selection is impaired for incongruent targets because they are associated with and retrieve conflicting responses (assuming the targets have been experienced with both tasks in the past), whereas it is facilitated for congruent targets because they are associated with and retrieve a unique response, with the result being a response congruency effect.

Recent studies have implicated both the mediated and nonmediated routes as sources of response congruency effects, although some evidence favors one route over the other in specific contexts. Evidence favoring the nonmediated route comes from studies in which inverted response congruency effects were found when category–response mappings were reversed, suggesting that targets were being used to retrieve responses directly from long-term memory (Schneider & Logan, in press; Waszak, Pfister, & Kiesel, 2013; Wendt & Kiesel, 2008). Evidence favoring the mediated route comes from studies in which response congruency effects were found with unpracticed target–response mappings (Liefooghe, Wenke, & De Houwer, 2012), irrelevant distractors never presented as targets (Reisenauer & Dreisbach, 2013), and nonrepeated targets (Schneider, 2015), all cases in which the nonmediated route was nonfunctional and categorization via the mediated route was the basis for response selection.

The study by Schneider (2015) is particularly relevant to the present investigation. In three experiments involving slightly different task-switching procedures, subjects performed living–nonliving and small–large tasks on a large set of target words, none of which were repeated during each experiment. The nonmediated route was nonfunctional for nonrepeated targets because there were no target–response instances from past experience to enable response selection via direct memory retrieval. The mediated route was functional for nonrepeated targets because categorization depended on preexisting knowledge of semantic associations (e.g., *frog* is living) and memory for the instructed category–response mappings (e.g., living requires a left keypress response), neither of which required experience responding to the targets. I observed robust response congruency effects for both RTs and error rates in all three experiments, indicating that the mediated route was sufficient to produce such effects by itself. The question of interest in the present study was whether response congruency effects generated by the mediated route are sensitive to proportion congruent manipulations.

To my knowledge, proportion congruent manipulations have been used in four previous task-switching studies, three of which dealt with response congruency effects. Meiran (1996, Experiment 3) manipulated the proportion of congruent trials between subjects for randomly intermixed up–down and left–right judgments of the spatial location of a happy face target in a grid. There were numerical but nonsignificant trends in the RT and error data for larger response congruency effects when trials were mostly congruent than when they were mostly incongruent. Fernandez-Duque and Knight (2008, Experiments 2A and 2B) manipulated the proportion of congruent trials within subjects in separate blocks for a color–word Stroop task that occurred in strict alternation with a numerical Stroop task (indicating the number of digits in a string of identical digits; e.g., *222*). Response congruency effects were not reported, but the color–word Stroop effect was larger when color–word Stroop trials were mostly congruent than when they were mostly incongruent, even when stimulus and motor priming were excluded as potential influences. Wendt, Luna-Rodriguez, Kiesel, and Jacobsen (2013) manipulated the proportion of congruent trials within subjects in separate halves of their experiments for a subset of digit targets for one of two randomly intermixed tasks (odd–even and small–large judgments). They found larger response congruency effects for the subset of test digits (which were always 50% congruent) when trials were mostly congruent than when they were mostly incongruent, but only for the task associated with the proportion congruent manipulation, suggesting some context sensitivity (see also Crump & Milliken, 2009). Braverman and Meiran (2015) manipulated the proportion of congruent trials within subjects in either separate blocks or for specific stimuli for randomly intermixed up–down and left–right judgments of semicircle targets. They found larger response congruency effects when trials were mostly congruent than when they were mostly incongruent, but the relevant interaction was significant only for the RT data in their Experiment 1 and for the error data in their Experiment 2.

Collectively, these previous task-switching studies provide some evidence that response congruency effects are sensitive to proportion congruent manipulations, but there are three considerations that limit the conclusions that can be drawn from them. First, the relevant interaction between response congruency and proportion congruent did not consistently reach statistical significance (Braverman & Meiran, 2015; Meiran, 1996). Second, given that all the studies involved small sets of frequently repeated targets, one cannot attribute the response congruency effects unequivocally to the mediated route for response selection, because direct retrieval via the nonmediated route was possible. Third, one cannot attribute the proportion congruent effects across all the studies unequivocally to either top-down control of attention or bottom-up control based on item-specific learning. Consequently, it is difficult to ascertain whether the mediated or the nonmediated route produced the response congruency effects and whether the proportion congruent manipulation affected behavior in a top-down or bottom-up manner, making it unclear how cognitive control was modulated during response selection.

The Present Study

The present study was designed to provide insight regarding proportion congruent effects related to response congruency in task switching and the cognitive mechanisms underlying such effects. I conducted a task-switching experiment involving the aforementioned living–nonliving and small–large judgments of target words, with the tasks randomly intermixed and the task categories mapped to overlapping responses to create congruent and incongruent targets. The proportion of congruent trials was manipulated between subjects at three levels: low (37.5%), medium (50.0%), and high (62.5%). Following Schneider (2015), I used a large set of target words, none of them repeated during the experiment.

This experimental design offers two major advantages over previous research. First, with the use of nonrepeated targets, response congruency effects can be attributed unequivocally to the mediated route, because the nonmediated route is nonfunctional. By extension, any changes in response congruency effects as a result of the proportion congruent manipulation can be linked to modulated functioning of the mediated route. Second, with the use of nonrepeated targets, proportion congruent effects can be attributed unequivocally to top-down control of attention, because bottom-up control based on item-specific learning is not possible. In tandem, these advantages allow one to interpret proportion congruent effects as reflecting top-down control of the mediated route for response selection, thereby enabling a more refined explanation of how cognitive control can affect response selection in conflict situations.

Method

Subjects

One hundred and twenty students from Purdue University participated for course credit. There were 40 subjects in each proportion congruent group (low, medium, and high). Data from six additional subjects were excluded for mean error rates exceeding a preset inclusion criterion of 20%. Sample size per group was based on a power analysis reported in Schneider (2015), which determined that 40 subjects would provide statistical power of .95 to detect a medium-sized response congruency effect.

Tasks and Stimuli

Two categorization tasks were performed on the referents of target words. The living–nonliving task (cued by the words *living–nonliving*) involved judging whether a target referred to something that was living or nonliving. A *living* thing was defined in the instructions as any organism, animal, insect, tree, plant, flower, fruit, or vegetable. The small–large task (cued by the words *small–large*) involved judging whether a target referred to something that was small or large relative to the size of a basketball. The targets were 320 words used previously by Schneider (2015), with 80 words for each combination of the living–nonliving and small–large categories. Targets were matched on word length and word frequency across categories. A random subset of 256 words was selected for each subject, with the proportion of targets from each category determined by the subject's proportion congruent group and category–response mappings. Cues and targets were displayed in white 18-point Courier New font on a black background of a computer monitor viewed from a distance of about 50 cm.

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 32 trials. Each trial began with two vertically arranged fixation crosses presented in the center of the screen. After 500 ms, the top and bottom crosses were replaced simultaneously by a cue and a target, respectively. Cue and target remained onscreen until the subject responded by pressing either the *D* key or the *K* key on a QWERTY keyboard. The next trial commenced after a blank screen was shown for 500 ms. Subjects were instructed to respond quickly and accurately.

Same-task categories were mapped to different responses (e.g., living and small categories mapped to the *D* key, nonliving and large categories mapped to the *K* key), and all possible category–response mappings were counterbalanced across subjects within each proportion congruent group. The left–right order of the category words composing the cues matched the left–right order of the responses for each subject (e.g., a subject with the large and small categories mapped to the *D* and *K* keys, respectively, had *large–small* as a cue). Response congruency for each target was defined by the category–response mappings. For example, if a subject had the living and small categories mapped to the *D* key and the nonliving and large categories mapped to the *K* key, then congruent targets would be living and small (e.g., *frog*) or nonliving and large (e.g., *stove*), and incongruent targets would be living and large (e.g., *camel*) or nonliving and small (e.g., *pebble*).

For subjects in the low, medium, and high proportion congruent groups, the proportions of congruent targets in the experiment were 37.5%, 50.0%, and 62.5%, respectively. Targets were selected randomly without replacement from each category such that the appropriate proportion of congruent trials was realized in every block. Subjects were informed that targets would never be repeated, but they were not told about the proportion congruent manipulation. Cues were selected randomly but constrained such that each task was performed equally often in every block and the proportion congruent manipulation was realized for each task separately. Because of the random selection of cues, task switches and task repetitions occurred randomly across trials.

Results

Proportion Congruent Analysis

The first block and the first trial of each subsequent block were excluded as practice. Trials with RTs more than 3 standard deviations above the condition-specific mean for a given subject were excluded (1.9% of trials). Error trials were excluded from the RT analysis. Mean RTs and error rates were submitted to 3 (proportion congruent: low, medium, or high) $\times$ 2 (response congruency: incongruent or congruent) $\times$ 2 (transition: task switch or task repetition) mixed-measures analyses of variance (ANOVAs), with proportion congruent as a between-subjects factor and the other variables as within-subject factors. All significant effects ($p < .05$) are reported here; selected nonsignificant effects are also reported. Mean RTs and error rates are provided in Table 1.

The RT data are plotted as a function of response congruency and proportion congruent in Figure 1A, with response congruency effects presented in Figure 1B for easier visualization. There was an overall response congruency effect of 30 ms, resulting in a significant main effect of response congruency, $F(1, 117) = 9.56$, $MSE = 11{,}055.41$, $p = .002$, $\eta_p^2 = .08$. The response congruency effect increased with proportion congruent (see Figure 1B), resulting in a significant Response Congruency $\times$ Proportion Congruent interaction, $F(2, 117) = 5.42$, $MSE = 11{,}055.41$, $p = .006$, $\eta_p^2 = .09$. Despite numerical differences in overall RT between proportion congruent groups, the main effect of proportion congruent was nonsignificant, $F(2, 117) = 0.83$, $MSE = 368{,}368.42$, $p = .44$, $\eta_p^2 = .01$. Task switches (1,536 ms) took longer than task repetitions (1,410 ms), resulting in a significant main effect of transition, $F(1, 117) = 115.99$, $MSE = 16{,}430.06$, $p < .001$, $\eta_p^2 = .50$. The response congruency effect was numerically but not reliably larger for task switches (39 ms) than for task repetitions (20 ms), as indicated by a nonsignificant Response Congruency $\times$ Transition interaction, $F(1, 117) = 1.00$, $MSE = 10{,}729.62$, $p = .32$, $\eta_p^2 < .01$.

The error data are plotted as a function of response congruency and proportion congruent in Figure 1C, with response congruency effects presented in Figure 1D. There was an overall response congruency effect of 3.2%, resulting in a significant main effect of response congruency, $F(1, 117) = 34.92$, $MSE = 34.54$, $p < .001$, $\eta_p^2 = .23$. The response congruency effect increased with proportion congruent (see Figure 1D), resulting in a significant Response Congruency $\times$ Proportion Congruent interaction, $F(2, 117) = 3.42$, $MSE = 34.54$, $p = .036$, $\eta_p^2 = .06$. The response congruency

Table 1
Mean Correct Response Times (in Milliseconds) and Mean Error Rates (as Percentages) as a Function of Proportion Congruent, Response Congruency, and Transition

Proportion congruent	Response congruency	Transition	Response time	Error rate
Low	Incongruent	Task switch	1,547 (52)	8.6 (1.1)
		Task repetition	1,422 (47)	5.1 (0.8)
	Congruent	Task switch	1,537 (54)	5.0 (0.7)
		Task repetition	1,449 (48)	4.9 (0.7)
Medium	Incongruent	Task switch	1,600 (52)	7.9 (1.1)
		Task repetition	1,443 (47)	6.2 (0.8)
	Congruent	Task switch	1,564 (54)	4.6 (0.7)
		Task repetition	1,421 (48)	4.6 (0.7)
High	Incongruent	Task switch	1,521 (52)	11.7 (1.1)
		Task repetition	1,395 (47)	6.9 (0.8)
	Congruent	Task switch	1,449 (54)	4.6 (0.7)
		Task repetition	1,330 (48)	3.7 (0.7)

Note. Values in parentheses are standard errors of the mean.

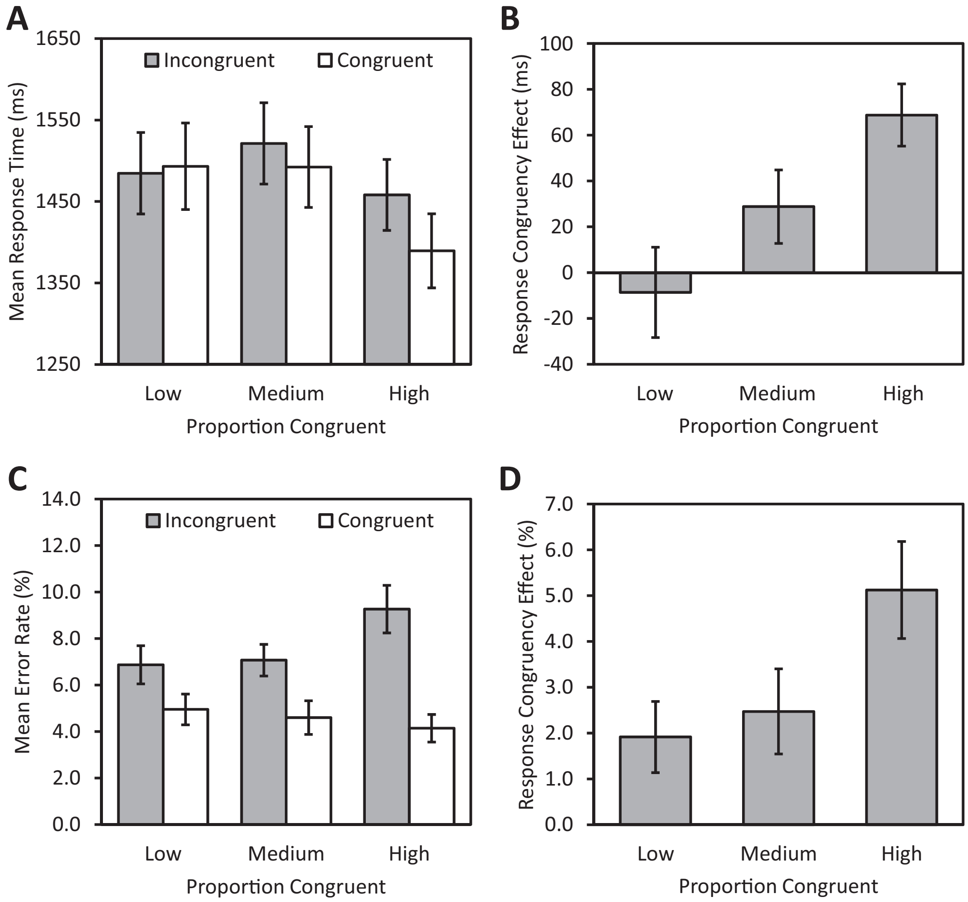

Figure 1. Mean response times and error rates for incongruent and congruent trials, with corresponding response congruency effects, as a function of proportion congruent. Error bars represent standard errors of the mean.

effect was larger for task switches (4.7%) than for task repetitions (1.7%), resulting in a significant Response Congruency × Transition interaction, $F(1, 117) = 20.76$, $MSE = 12.79$, $p < .001$, $\eta_p^2 = .15$. Task switches (7.1%) produced more errors than did task repetitions (5.2%), resulting in a significant main effect of transition, $F(1, 117) = 33.04$, $MSE = 12.38$, $p < .001$, $\eta_p^2 = .22$. The switch cost was smallest for the medium proportion congruent group (0.8%), intermediate for the low proportion congruent group (1.8%), and largest for the high proportion congruent group (2.9%), resulting in a significant Transition × Proportion Congruent interaction, $F(2, 117) = 3.33$, $MSE = 12.38$, $p = .039$, $\eta_p^2 = .05$. None of the interactions involving transition in the error data were significant in the RT data.

Sequential Congruency Analysis

Previous research has revealed evidence of sequential congruency effects in the form of a smaller congruency effect following an incongruent than a congruent trial (Gratton, Coles, & Donchin, 1992; for reviews, see Braem, Abrahamse, Duthoo, & Notebaert, 2014; Egner, 2014). In task-switching situations, sequential congruency effects have been observed for task repetitions but not for task switches (e.g., Kiesel, Kunde, & Hoffmann, 2006; Wendt et al., 2013).

To determine whether sequential congruency effects occurred in the present experiment, the data were reanalyzed after the additional exclusion of trials immediately preceded by errors (to prevent contamination from any posterror effects). Mean RTs and error rates were submitted to 3 (proportion congruent: low, medium, or high) × 2 (current response congruency [on Trial n]: incongruent or congruent) × 2 (previous response congruency [on Trial $n - 1$]: incongruent or congruent) × 2 (transition: task switch or task repetition) mixed-measures ANOVAs, with proportion congruent as a between-subjects factor and the other variables as within-subject factors. To avoid redundancy with the proportion congruent analysis, only those significant effects ($p < .05$) involving previous response congruency are reported here; selected nonsignificant effects are also reported. Mean RTs and error rates are provided in Table 2, collapsed over proportion congruent because it was not involved in any significant interactions with previous response congruency.

For the RT data, there were no significant effects involving previous response congruency. The response congruency effect

Table 2
Mean Correct Response Times (in Milliseconds) and Mean Error Rates (as Percentages) as a Function of Transition, Previous Response Congruency, and Current Response Congruency

Transition	Previous response congruency	Current response congruency	Response time	Error rate
Task switch	Incongruent	Incongruent	1,560 (31)	9.9 (0.9)
		Congruent	1,518 (33)	5.0 (0.5)
	Congruent	Incongruent	1,518 (29)	9.3 (0.8)
		Congruent	1,503 (33)	4.5 (0.5)
Task repetition	Incongruent	Incongruent	1,411 (31)	4.6 (0.5)
		Congruent	1,388 (28)	4.7 (0.5)
	Congruent	Incongruent	1,418 (27)	6.7 (0.6)
		Congruent	1,389 (31)	3.8 (0.5)

Note. Values in parentheses are standard errors of the mean.

was numerically smaller when the previous trial was incongruent (23 ms) than when it was congruent (29 ms) for task repetitions, whereas the opposite pattern (42 ms vs. 15 ms, respectively) was observed for task switches. However, the Current Response Congruency × Previous Response Congruency interaction was nonsignificant, $F(1, 117) = 0.38$, $MSE = 19{,}159.64$, $p = .54$, $\eta_p^2 < .01$, as was the Current Response Congruency × Previous Response Congruency × Transition interaction, $F(1, 117) = 0.71$, $MSE = 22{,}816.97$, $p = .40$, $\eta_p^2 < .01$.

For the error data, there were significant effects involving previous response congruency, modulated by transition. The response congruency effect was smaller when the previous trial was incongruent (−0.1%) than when it was congruent (2.9%) for task repetitions, but little difference (5.0% vs. 4.8%, respectively) was observed for task switches. The Current Response Congruency × Previous Response Congruency interaction was significant, $F(1, 117) = 4.28$, $MSE = 28.98$, $p = .04$, $\eta_p^2 = .04$, as was the Current Response Congruency × Previous Response Congruency × Transition interaction, $F(1, 117) = 6.80$, $MSE = 23.96$, $p = .01$, $\eta_p^2 = .06$.

Discussion

In the present experiment, subjects repeated and switched between living–nonliving and small–large judgments of target words that were either congruent or incongruent (mapped to the same or different responses across tasks), with the proportion of congruent trials manipulated between subjects. Targets were not repeated during the experiment, making the nonmediated route for response selection nonfunctional and leaving the mediated route as the sole mechanism for producing response congruency effects. Moreover, the absence of target repetition precluded bottom-up control based on item-specific learning, leaving top-down control of attention as the sole mechanism for producing proportion congruent effects.

The experiment yielded three effects that were consistent across the RT and error data. First, there were switch costs in performance (see Table 1), consistent with the results of previous task-switching experiments with these tasks (e.g., Arrington & Logan, 2004; Schneider, 2015; Schneider & Logan, 2007, 2015). Second, there were overall response congruency effects (see Figure 1), replicating previous findings with nonrepeated targets (Schneider, 2015) and implicating the mediated route in response selection. Third, the response congruency effects increased with proportion congruent (see Figure 1), replicating previous findings of proportion congruent effects in task-switching situations (Braverman & Meiran, 2015; Meiran, 1996; Wendt et al., 2013) and in other contexts (e.g., Lindsay & Jacoby, 1994; Logan, 1980; Logan & Zbrodoff, 1979; Logan et al., 1984; Lowe & Mitterer, 1982; for reviews, see Bugg, 2012; Bugg & Crump, 2012), with the novel twist of no target repetition.

The finding of overall response congruency effects with nonrepeated targets is important for two reasons. First, the nonmediated route for response selection is nonfunctional in the absence of target repetition, because there are no target–response instances from past experience available for direct memory retrieval, leaving categorization via the mediated route as the basis for response selection. Together with the results of Schneider (2015), the present results demonstrate that the mediated route is sufficient to produce response congruency effects by itself. This demonstration is important because it informs theoretical accounts of response selection in task-switching situations. It challenges computational models of task switching that either do not fully implement a mediated route (e.g., Sohn & Anderson, 2001) or produce response congruency effects solely by a nonmediated route (e.g., Altmann & Gray, 2008), whereas it supports models that select responses by a mediated route (e.g., Schneider, 2014; Schneider & Logan, 2005, 2009). However, it does not rule out a potential contribution of the nonmediated route to response congruency effects in task-switching situations with small sets of frequently repeated targets. Various ways in which the mediated and nonmediated routes might be combined in response selection have been proposed (Schneider, 2014; Schneider & Logan, 2014), setting the stage for future model development.

The second reason why the finding of overall response congruency effects is important follows from the first. Given that the response congruency effects in the present experiment can be attributed unequivocally to the mediated route, a critical inference is that subjects must have engaged in dual-task processing by categorizing the target with respect to both tasks on many trials, despite only one task being cued on each trial. An important implication is that nominal task switching likely did not involve complete mental task-set switching (see Schneider & Logan, 2005), blurring the distinction between task switches and task repetitions. Dual-task processing may help to explain why the interaction between response congruency and transition was inconsistent across the RT and error data. The response congruency effect was significantly larger for task switches than for task repetitions in the error data, whereas the interaction was nonsignificant (but in the same direction) in the RT data. In previous experiments involving the same tasks and stimuli, Schneider (2015) obtained a significant interaction between response congruency and transition only for error rate in one experiment. Moreover, the interaction has been inconsistent in studies involving other tasks and stimuli (e.g., Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Monsell et al., 2003). The mixed results may reflect dual-task processing on both task-switch and task-repetition trials, making the transitions more similar at a cognitive level and attenuating interactions between response congruency and transition, possibly to the point that they become nonsignificant in some experiments.

The finding that response congruency effects increased with proportion congruent is particularly informative because it represents a listwide proportion congruent effect that cannot be explained by item-specific learning. Even though subjects may have learned whether a given target was experienced in a low, medium, or high proportion congruent context, item-specific knowledge could not have been used, because targets were never repeated, providing no opportunity for target–response or target–congruency associations to affect subsequent behavior. In contrast, subjects must have learned about the global proportion congruent context in which targets were presented and used that explicit or implicit knowledge to adjust their cognitive processing.[1] Consequently, bottom-up control accounts of proportion congruent effects cannot accommodate the present data (e.g., Bugg et al., 2008; Jacoby et al., 2003), whereas top-down control accounts remain viable (e.g., Bugg, 2014; Bugg & Chanani, 2011; Logan, 1980; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982).

This conclusion is consistent with an idea proposed recently by Bugg (2014), who hypothesized that the availability of consistent target–response associations moderates the engagement of top-down control mechanisms in conflict situations. When item-specific learning leads to target–response associations that can be accessed reliably from memory when a given target is encountered again, bottom-up control will dominate top-down control in determining proportion congruent effects. However, when target–response associations are weak or nonexistent, top-down control is more likely to be engaged as a "last resort" to guide response selection (Bugg, 2014, p. 583). Bugg (2014) reviewed evidence and presented new data in support of her hypothesis, which seems to fit well with the present study because direct target–response associations were not available when selecting responses, thereby motivating engagement of top-down control.

Bugg's (2014) hypothesis about the relationship between cognitive control and proportion congruent effects can be integrated with proposed mechanisms of response selection in task switching to generate interesting predictions. The nonmediated route for response selection becomes functional only when item-specific learning leads to target–response associations that can be accessed reliably from memory when a given target is encountered again—the same circumstances under which Bugg (2014) argued that bottom-up control determines proportion congruent effects. This leads to the prediction of item-specific proportion congruent effects when the nonmediated route can contribute to response congruency effects, which is possible in task-switching situations with small sets of frequently repeated targets. However, as target set size increases and target repetition becomes less frequent, there is likely to be a shift from the nonmediated route to the mediated route as the main contributor to response congruency effects and a shift from bottom-up to top-down control as the main contributor to proportion congruent effects. This leads to the prediction of smaller item-specific proportion congruent effects at larger target set sizes, possibly coupled with the emergence of item-nonspecific, listwide proportion congruent effects. In the extreme case of a large target set and no target repetition, as in the present experiment, the nonmediated route becomes nonfunctional, and item-specific proportion congruent effects become impossible, resulting in the mediated route being the sole contributor to response congruency effects and top-down control being engaged to yield listwide proportion congruent effects, perhaps based on monitoring of response conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001).

The idea that top-down control may be linked to conflict monitoring suggests that proportion congruent effects might be accompanied by sequential congruency effects, even though the effects can be dissociated (e.g., Torres-Quesada, Funes, & Lupiáñez, 2013; Torres-Quesada, Lupiáñez, Milliken, & Funes, 2014) and may reflect different levels of temporal context (Egner, 2014). The present experiment provided some evidence in support of an association (see Table 2): A significant sequential congruency effect was observed for task repetitions but not for task switches in the error data, consistent with previous transition-contingent findings (e.g., Kiesel et al., 2006; Wendt et al., 2013). The relevant interactions were nonsignificant in the RT data, but the numerical pattern took the form of a standard sequential congruency effect for task repetitions and a reversed sequential congruency effect for task switches, a pattern that has been observed in past studies (Brown et al., 2007; Notebaert & Verguts, 2008). The absence of target repetition in the experiment rules out stimulus-based priming accounts of sequential congruency effects (Mayr, Awh, & Laurey, 2003) and supports generalized accounts in which conflict monitoring leads to item-nonspecific, top-down control adjustments (Botvinick et al., 2001; Verguts & Notebaert, 2008).

What is the nature of the top-down control? As discussed earlier, it has been suggested that top-down control involves dividing attention between relevant and irrelevant stimulus features (Logan, 1980; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982). In the Stroop task, top-down control could be implemented by allocating more attention to ink color than to word identity (or their associated processes) when trials are mostly incongruent than when they are mostly congruent. In the present experimental context, top-down control could be implemented by allocating more attention to task-relevant categories than to task-irrelevant categories when trials are mostly incongruent than when they are mostly congruent. Given that the cue presented on each trial indicates the task-relevant categories (e.g., the *living–nonliving* cue indicates that the target is to be categorized as living or nonliving), changing how attention is divided between the cue and the target might be a way of accomplishing this objective. When targets are mostly incon-

[1] Subjects were not asked to estimate the proportion of congruent trials at the end of the experiment, so it is unknown whether they had explicit knowledge of that context.

gruent, it would be advantageous to allocate more attention to the cue than to the target in an effort to reduce conflict in response selection. When targets are mostly congruent, it would be advantageous to allocate more attention to the target than to the cue in an effort to benefit from consistency in response selection. Evidence in partial support of the second point comes from Schneider and Logan (2014, in press), who found that presenting the target before the cue—a situation in which attention would initially be allocated completely to the target—led to substantial improvements in performance for congruent targets. Notably, subjects sometimes responded correctly to a congruent target before the cue was presented, indicating that they took advantage of the consistency in response selection afforded by congruent targets. Early responding to incongruent targets was extremely rare, undoubtedly because subjects had to wait for the cue and allocate attention to it to resolve the conflict in response selection.

Changing how attention is allocated to the cue and the target entails giving more or less emphasis to task-relevant and task-irrelevant categories during response selection, implicating attentional control of the mediated route by which the stimuli are categorized. The mediated route could be controlled by having attentional weights on categorical evidence or activation from the cue and the target. These weights could be modified as the proportion of congruent targets is manipulated, perhaps in relation to the level of response conflict experienced, resulting in the categorical stimulus representations making unequal and changing contributions to the response selection process. There are different ways in which this idea might be realized in existing computational models, ranging from incorporating attentional control into a model of the mediated route (e.g., compound cue retrieval; Logan & Schneider, 2010; Schneider, 2014; Schneider & Logan, 2005, 2009, 2014) to implementing a mediated route in a model of conflict-modulated learning of attentional control (e.g., Blais & Verguts, 2012; Verguts & Notebaert, 2008; see also Jiang, Heller, & Egner, 2014). Modeling efforts in this vein could potentially account for the present results and provide a refined understanding of how cognitive control enables appropriate behavior in ambiguous contexts that afford different thoughts and actions.

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