Research Report

Contextual Adjustments in Cognitive Control Across Tasks

Antonio L. Freitas, Michal Bahar, Shan Yang, and Ruslan Banai

State University of New York at Stony Brook

ABSTRACT—*Does encountering information-processing conflict recruit general mechanisms of cognitive control or change only the representations of specific cues and responses? In the present experiments, a flanker task elicited responses to symbolic information (arrow meaning), whereas Stroop-like tasks elicited responses to nonsymbolic information (color of a letter or location of a target box). Despite these differences, when participants performed the flanker and Stroop tasks intermittently in randomized orders, the extent of information-processing conflict encountered on a particular trial modulated performance on the following trial. On across-task trial pairs, increases in response time to incongruent relative to congruent stimulus arrays were smaller immediately following incongruent trials than immediately following congruent trials. The degree of cognitive control exerted on a particular task thus appears to reflect not only the quality, but also the quantity, of recent experiences of information-processing conflict.*

Control of thought and control of action are hallmarks of effective human behavior. To account for how these processes are themselves controlled, Botvinick, Braver, Barch, Carter, and Cohen (2001) have proposed the conflict-monitoring theory, which states that detection of conflict in information processing, as when cross talk between different processing streams implicates incompatible responses, activates cognitive control.

Conflict-monitoring theory proposes that in a process termed *conflict adaptation*, the extent of cognitive control exerted at a particular time will be adapted to the extent of information-processing conflict experienced most recently. Findings obtained with flanker tasks (which elicit responses to a central stimulus flanked by congruent or incongruent stimuli; Gratton, Coles, & Donchin, 1992) support this view. Increases in response time (RT) to incongruent relative to congruent flanker arrays are smaller on trials immediately following incongruent trials (a finding consistent with the conflict-adaptation assumption that cognitive control has already been engaged) than on trials immediately following congruent trials (a finding consistent with the conflict-adaptation assumption that cognitive control must be engaged anew). Some recent investigations have supported this conflict-adaptation view (Ullsperger, Bylsma, & Botvinick, 2005; Verbruggen, Notebaert, Liefooghe, & Vandierendonck, 2006); however, others have suggested that putative conflict-adaptation effects often reflect nothing more than retrieval advantages for specific cue-response pairs (i.e., repetition priming; Mayr, Awh, & Laurey, 2003; Nieuwenhuis et al., 2006).

In the study reported here, we examined cognitive control across tasks. If separate tasks involve distinct cues, rules, and responses, then across-task effects of information-processing conflict at trial $n - 1$ on trial n responses should reflect general cognitive-control adaptation rather than specific cue-response priming. We first examined conflict adaptation within a single (flanker) task, while varying stimulus orientation (horizontal vs. vertical) to facilitate analyzing only stimulus nonrepetitions.[1] We then randomly interspersed flanker trials with trials of Stroop tasks (see MacLeod, 1991), which elicited responses to perceptual information (letter color in Experiment 2; location of a target box in Experiment 3) accompanying congruent or incongruent symbolic information (match or mismatch between the color of the font and the color word's meaning, in Experiment 2; arrow pointing toward or away from the target box, in Experiment 3). We tested whether information-processing conflict would modulate performance across the tasks, as would be predicted in the case of conflict adaptation, but not repetition priming.

Address correspondence to Antonio L. Freitas, Department of Psychology, State University of New York, Stony Brook, NY 11794-2500, e-mail: antonio.freitas@sunysb.edu.

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[1]Mayr et al. (2003) did not find conflict-adaptation effects when stimulus repetitions were addressed in this way, in experiments in which flanker stimuli remained visible throughout each trial (U. Mayr, personal communication, November 21, 2006). In our Experiment 1, flanker exposure was limited to 300 ms. We anticipated that any differences between our results and those of Mayr et al. might reflect this methodological difference, in that the prolonged stimulus exposures used by Mayr et al. can be hypothesized to have strengthened stimulus-specific repetition-priming effects, to the detriment of more general conflict-adaptation effects.

METHOD

In each of three experiments, trials began with presentation of a fixation symbol for 1,250 ms, followed by a blank screen for 250 ms. Critical stimulus arrays ($4.76° \times 4.76°$ visual angle) then appeared in randomized orders (see Fig. 1). At the end of each presentation of the critical stimulus, the screen went blank until a response was recorded. Each experiment comprised 288 trials, divided into three blocks. Errors cued a 250-ms tone. Responses were analyzed only for trials in which the task (Stroop vs. flanker, in Experiments 2 and 3) or the flanker orientation (horizontal vs. vertical, in Experiment 1) differed from that of the previous trial.

Participants in Experiment 1 were 51 undergraduates (25 males), who responded to horizontally and vertically oriented flanker stimuli presented for 300 ms. Participants were instructed to press standard computer keys to indicate the direction in which the center arrow pointed.

In Experiment 2, 32 native-English-speaking undergraduates (15 males) responded vocally (via microphones atop their computer monitors, within sound-attenuating chambers) to horizontal flanker stimuli and Stroop color stimuli (the words "RED" and "GREEN" in red or green font). Participants were instructed to say aloud the direction in which the central arrow pointed (flanker task) and the color of the printed word (Stroop color task). In the flanker task, flanking arrows appeared 100 ms before the central arrow and remained visible, with the central arrow, for 400 ms. In the Stroop task in Experiment 2, color words were presented initially in black font for 100 ms; then the
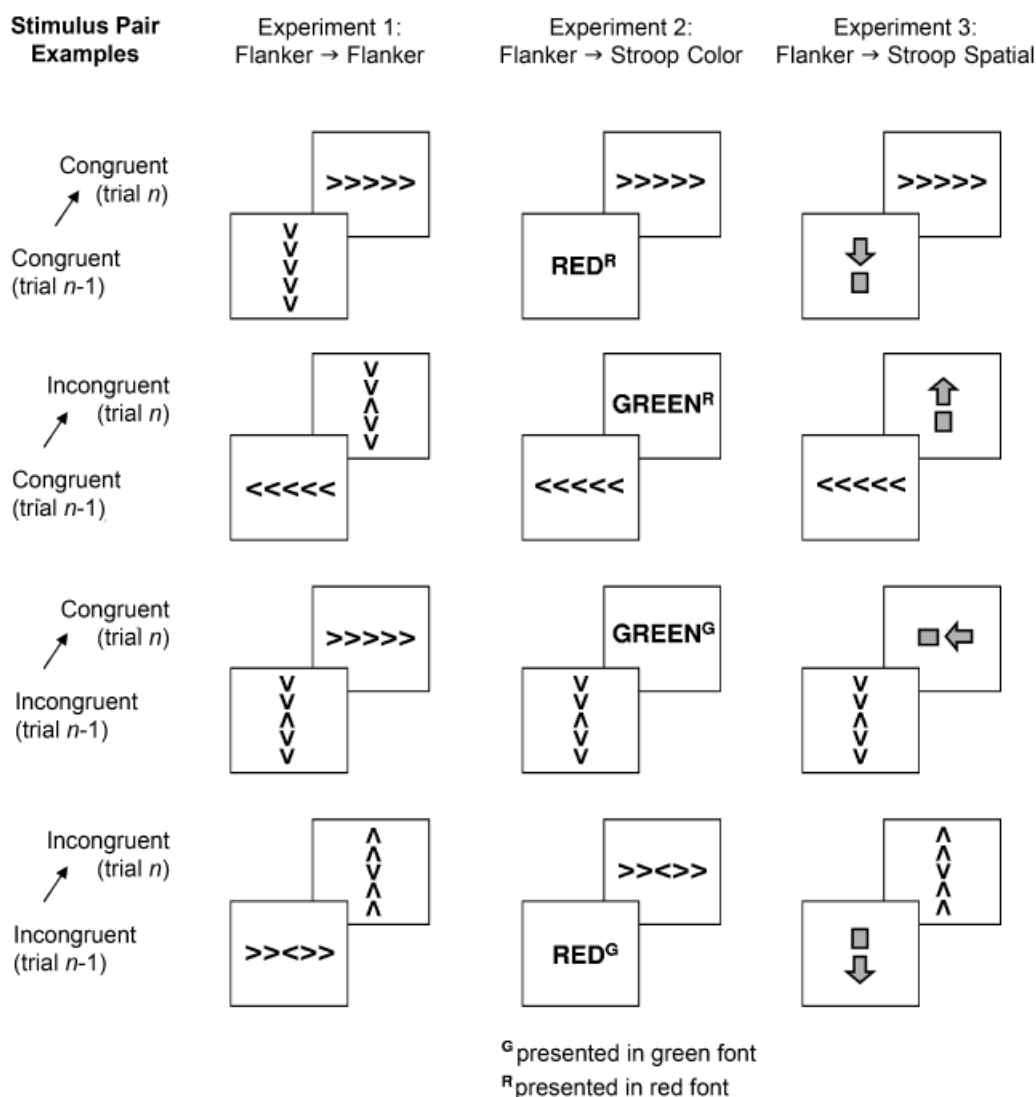
Fig. 1. Examples of the stimuli on successive trials in each experiment. All possible combinations of task and stimulus types were used in equal proportions and were presented in randomized orders. After the experiments, trials were recoded to denote which trial types preceded them, yielding the four trial-pair categories exemplified here. In the flanker task, participants indicated the direction in which the central arrow pointed. In the Stroop tasks, participants indicated the color in which the word was printed (Experiment 2) or the location of the target box relative to the arrow (Experiment 3).
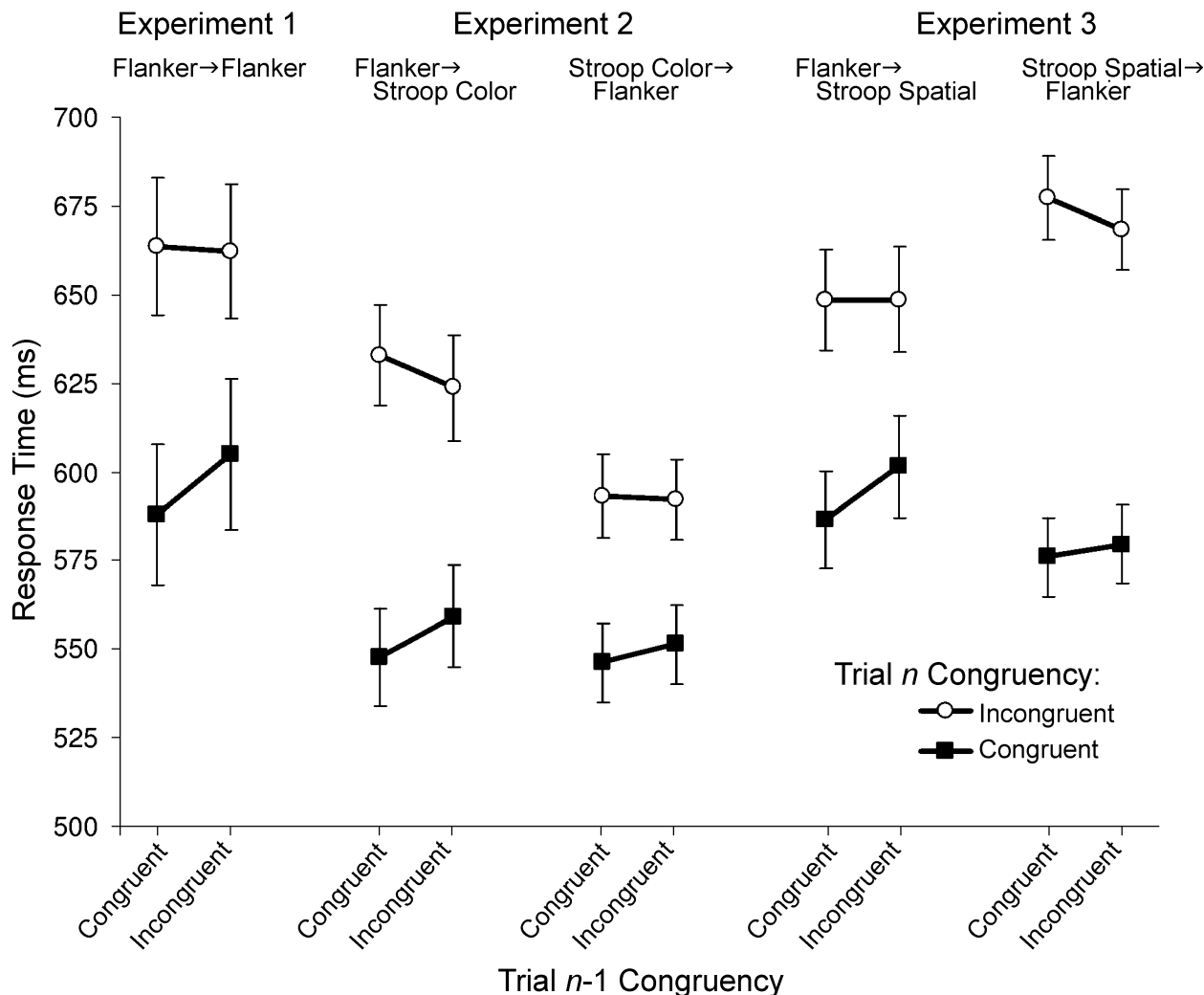
Fig. 2. Average response times at trial *n* on the flanker and Stroop tasks as a function of congruency of the stimulus arrays on trial *n* and trial *n* − 1. Error bars represent standard errors of the means.

same words were presented in red or green font and remained visible for 400 ms. Voice-recognition software determined response accuracy and cued error feedback.

In Experiment 3, 52 undergraduates (23 males) responded via joysticks to flanker and Stroop spatial stimuli that were displayed on different axes (i.e., horizontal for one task and vertical for the other, counterbalanced across participants) so that across-task trial pairs required different responses. Stimulus arrays were presented for 300 ms. Participants were instructed to move the joystick to indicate either the direction in which a central arrow pointed (flanker task) or the location of a target box relative to an accompanying arrow (Stroop spatial task).

RESULTS

RTs less than 250 ms or greater than 1,000 ms (3.88% of all trials) and error trials and trials immediately following error trials (4.95% of the total) were not analyzed. In separate repeated measures analyses of variance (ANOVAs) of the RTs, significant

interactions between congruency on trial *n* and congruency on trial *n* − 1 (the critical conflict-adaptation prediction) emerged for Experiment 1, $F(1, 50) = 10.97$, $p_{\text{rep}} = .98$, $\eta_p^2 = .18$; Experiment 2, $F(1, 31) = 6.14$, $p_{\text{rep}} = .93$, $\eta_p^2 = .17$; and Experiment 3, $F(1, 51) = 19.05$, $p_{\text{rep}} > .99$, $\eta_p^2 = .27$ (see Fig. 2). There were no significant effects of conflict adaptation on error rates in these experiments ($Fs < 1.19$).[2]

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[2]In follow-up studies of the flanker task using procedures identical to those of Experiment 1 except as noted, we observed within-task conflict-adaptation effects on error rates, $F(1, 48) = 6.98$, $p_{\text{rep}} = .95$, $\eta_p^2 = .13$, and RTs, $F(1, 48) = 24.57$, $p_{\text{rep}} > .99$, $\eta_p^2 = .34$, when flanker orientation alternated systematically ($N = 49$), rather than randomly, as in Experiment 1. We also observed within-task conflict-adaptation effects on error rates, $F(1, 54) = 18.09$, $p_{\text{rep}} > .99$, $\eta_p^2 = .25$, and RTs, $F(1, 54) = 11.68$, $p_{\text{rep}} = .945$, $\eta_p^2 = .18$, when participants ($N = 56$) used joysticks to complete the task, and flanker orientation varied randomly for half the participants and alternated systematically for the other half. Overall, our results suggest that response latency is likely to show conflict-adaptation effects both within and across tasks (an effect that may reflect general engagement of cognitive control), but that response accuracy may show conflict-adaptation effects only within the same task (an effect that may reflect preparation of specific cue-response mappings).

Given that these ANOVAs included only across-task (Experiments 2 and 3) and across-orientation (Experiment 1) trial pairs, there were no stimulus repetitions between trial n and trial $n - 1$. There were, however, lagged stimulus repetitions between trial n and trial $n - 2$, and such repetitions have been found to facilitate RT on trial n (Mayr et al., 2003). Moreover, as a separate issue, stimulus-array congruency and RT on trial $n - 1$ can be expected to covary significantly (because responses are slower on incongruent than on congruent trials). Accordingly, effects of trial $n - 1$ stimulus-array congruency on trial n RT could reflect other factors indexed by trial $n - 1$ RT, such as fatigue or self-pacing. Thus, it was important to determine whether stimulus-array congruency on trial $n - 1$ modulated RT on trial n independently of any covariation between RTs on trial n and trial $n - 1$.

Accordingly, we analyzed RTs through hierarchical linear modeling (using SAS PROC MIXED; Littell, Milliken, Stroup, & Wolfinger, 1996), which can model individual-trial data as a function of general trial information (i.e., congruency on trial n and on trial $n - 1$, each coded 0 or 1; the product of these two variables, which is the interaction term; and lagged stimulus repetition between trial n and trial $n - 2$, coded 0 or 1) and idiosyncratic trial information (i.e., RT on trial $n - 1$ and on trial $n - 2$). In analyses that simultaneously considered these six explanatory variables, the interaction between trial n congruency and trial $n - 1$ congruency remained significant in each experiment, $b = -13.55$, $SE = 3.82$, $t(6953) = 3.55$, $p_{rep} = .99$; $b = -12.31$, $SE = 6.29$, $t(4056) = 1.96$, $p_{rep} = .88$; and $b = -14.27$, $SE = 4.39$, $t(6990) = 3.25$, $p_{rep} = .985$, for Experiments 1, 2, and 3, respectively). There also was a unique effect of lagged stimulus repetition, $b = -11.58$, $SE = 3.18$, $t(6953) = 3.64$, $p_{rep} = .99$; $b = -17.57$, $SE = 4.90$, $t(4056) = 3.59$, $p_{rep} = .99$; $b = -19.84$, $SE = 3.75$, $t(6990) = 5.30$, $p_{rep} > .99$. Finally, there also were unique effects of trial $n - 1$ and trial $n - 2$ RT (all $ts > 3.80$, $p_{reps} > .99$).

DISCUSSION

Whereas the flanker task entailed responding to symbolic information (arrow meaning), the Stroop tasks entailed responding to nonsymbolic information (letter color or location of the target box). Despite these differences, on across-task trial pairs, stimulus-array congruency on trial $n - 1$ differentially affected RTs to incongruent versus congruent stimulus arrays on trial n. To our knowledge, these experiments provide the first evidence of across-task conflict adaptation. Engagement of cognitive control appears to have been determined by not only the quality, but also the quantity of recent experiences of information-processing conflict. While strongly supporting the conflict-monitoring theory (Botvinick et al., 2001) outlined in our introduction, these experiments also demonstrated unique facilitative effects of lagged stimulus repetition (Mayr et al., 2003). This use of hierarchical modeling procedures to simultaneously estimate ap-

parently top-down (conflict adaptation) and bottom-up (repetition priming) effects suggests the potential of this method to help integrate divergent theories into comprehensive accounts of cognitive control (see also Rouder & Lu, 2005).

In summary, the present results implicate a coherent mechanism of cognitive control that, once engaged, appears to be impressively flexible, applicable to various tasks and stimuli. Research using brain-imaging methods to examine across-task conflict adaptation would be useful for investigating the functional components of cognitive control that allow this flexibility. For instance, given recent evidence of context-specific functional connectivity between medial and lateral prefrontal regions, as well as anterior cerebellar regions (Egner & Hirsch, 2005), it would be important to examine whether, once engaged, brain areas associated with core functions of cognitive control, such as readying response inhibition and heightening sensory discrimination, transcend the task-specific content of information processing to coordinate responses to the overall degree of conflict.

REFERENCES

Botvinick, M.M., Braver, T.S., Barch, D.M., Carter, C.S., & Cohen, J.D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*, 624–652.

Egner, T., & Hirsch, J. (2005). The neural correlates and functional integration of cognitive control in a Stroop task. *NeuroImage*, *24*, 539–547.

Gratton, G., Coles, M.G.H., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General*, *121*, 480–506.

Littell, R.C., Milliken, G.A., Stroup, W.W., & Wolfinger, R.D. (1996). *SAS system for mixed models*. Cary, NC: SAS Institute.

MacLeod, C.M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin*, *109*, 163–203.

Mayr, U., Awh, E., & Laurey, P. (2003). Conflict adaptation effects in the absence of executive control. *Nature Neuroscience*, *6*, 450–452.

Nieuwenhuis, S., Stins, J.F., Posthuma, D., Polderman, T.J.C., Boomsma, D.I., & De Geus, E.J. (2006). Accounting for sequential trial effects in the flanker task: Conflict adaptation or associative priming? *Memory & Cognition*, *34*, 1260–1272.

Rouder, J.N., & Lu, J. (2005). An introduction to Bayesian hierarchical models with an application in the theory of signal detection. *Psychonomic Bulletin & Review*, *12*, 573–604.

Ullsperger, M., Bylsma, L.M., & Botvinick, M. (2005). The conflict-adaptation effect: It's not just priming. *Cognitive, Affective and Behavioral Neuroscience*, *5*, 467–472.

Verbruggen, F., Notebaert, W., Liefooghe, B., & Vandierendonck, A. (2006). Stimulus and response conflict-induced cognitive control in the flanker task. *Psychonomic Bulletin & Review*, *13*, 328–333.