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More conflict does not trigger more adjustment of cognitive control for subsequent events: A study of the bivalency effect

Alodie Rey-Mermet, Beat Meier *

Institute of Psychology and Center for Cognition, Learning, and Memory, University of Bern, Farbrikstr. 8, 3012 Bern, Switzerland

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Encountering a conflict triggers an adjustment of cognitive control. This adjustment of cognitive control can even affect subsequent performance. The purpose of the present study was to determine whether more conflict triggers more adjustment of cognitive control for subsequent performance. To this end, we focussed on the bivalency effect, that is, the adjustment of cognitive control following the conflict induced by bivalent stimuli (i.e., stimuli with relevant features for two tasks). In two experiments, we tested whether the amount of conflict triggered by bivalent stimuli affected the bivalency effect. Bivalent stimuli were either compatible (i.e., affording one response) or incompatible (i.e., affording two different responses). Thus, compatible bivalent stimuli involved a task conflict, whereas incompatible bivalent stimuli involved a task and a response conflict. The results showed that the bivalency effect was not affected by this manipulation. This indicates that more conflict does not trigger more adjustment of cognitive control for subsequent performance. Therefore, only the occurrence of conflict – not its amount – is determinant for cognitive control.

1. Introduction

Cognitive control refers to the ability to select task-relevant features while suppressing distracting ones in the face of conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004). Specifically, encountering a conflict induces an adjustment of cognitive control for the conflict-loaded trial as well as for subsequent performance (e.g., Botvinick et al., 2001; Egner, 2007; Woodward, Meier, Tipper, & Graf, 2003). So far, it is unclear whether the characteristics of the conflict – such as its amount – would affect the adjustment of cognitive control for subsequent performance. The present study is the first to investigate this question.

In their seminal account, Botvinick et al. (2001) proposed that once a conflict is detected, an adjustment of cognitive control is triggered, which can linger across subsequent trials. Importantly, they assumed that the adjustment of cognitive control "conveys only a very nonspecific type of information, indicating that the conflict has occurred in some unspecified form at some unspecified point" (p. 645). Accordingly, the characteristics of conflict are not determinant to trigger an adjustment of cognitive control.

Recent research, however, does not seem to support this claim when the characteristic is the *source of conflict* (see Egner, 2008). In those studies in which Stroop and Flanker tasks were intermixed[1], the results showed that responding to a Stroop conflict triggered an adjustment of cognitive control on subsequent performance only when the subsequent trials were Stroop trials, but not Flanker trials (see, e.g., Egner, Delano, & Hirsch, 2007; Funes, Lupiáñez, & Humphreys, 2010; Notebaert & Verguts, 2008; Schlaghecken, Refaat, & Maylor, 2011). This finding was interpreted as the result of an adjustment of cognitive control affected by the source of conflict (Egner, 2008).

* Corresponding author at: Institute of Psychology, University of Bern, Farbrikstr. 8, 3012 Bern, Switzerland.
E-mail address: beat.meier@psy.unibe.ch (B. Meier).

[1] In the Stroop task, participants are usually asked to indicate the color of a color word. For some stimuli, the color and the word are congruent (e.g., the word "red" written in red); for some other stimuli, the color and the word are incongruent (e.g., the word "red" written in blue). In the Flanker task, stimuli consist of strings of letters (e.g., HHH or SHS), and participants are asked to indicate the identity of the central letter. Congruent Flanker stimuli are letter strings in which the central and flanking letters are the same (e.g., HHH); incongruent Flanker stimuli are letter strings in which the central letter is different from the flanking letters (e.g., SHS). In both tasks, the results typically showed a congruence effect (i.e., a performance decrement on incongruent trials compared to congruent trials) and a congruence sequence effect (i.e., a reduction of the congruence effect after incongruent trials). The congruence sequence effect has been mainly explained by an adjustment of cognitive control, which is caused by the conflict induced by incongruent trials and which persists across subsequent trials (see Botvinick et al., 2001; Egner, 2007; Ullsperger, Bylsma, & Botvinick, 2005). However, it must be noted that this effect has also been assumed to result from other properties of incongruent stimuli than their conflict (e.g., their low perceptual fluency, see Dreisbach & Fischer, 2011; their aversive signal, see Dreisbach & Fischer, 2012; their contingency bias, see Schmidt & De Houwer, 2011; or the false expectations they induced, see Gratton, Coles, & Donchin, 1992).

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The source of conflict is not the only characteristic of conflict. Another characteristic may be the *amount of conflict*. In previous studies, the amount of conflict has been found to affect the adjustment of cognitive control but only for the conflict-loaded trial. For example, when simulating a Flanker task, conflict was measured as the product of the activation of the competing responses induced by the central and flanking letters. Thus, its amount varied on each trial, depending on each activation level. The simulations revealed that reaction times (RTs) for response execution increased when the product of the activation of the competing responses – the amount of conflict – increased (e.g., Yeung, Botvinick, & Cohen, 2004; Yeung, Cohen, & Botvinick, 2011). Another way to manipulate experimentally the amount of conflict was to present either compatible or incompatible bivalent stimuli (Rogers & Monsell, 1995; Steinhauser & Hübner, 2007, 2009). Bivalent stimuli are stimuli with relevant features for two different tasks. When participants are asked, for example, to switch between a color decision (red vs. blue) and a case decision (uppercase vs. lowercase), red or blue letters are bivalent stimuli because both color and case decisions can be performed. Thus, per definition, bivalent stimuli involve a *task* conflict. Moreover, when participants are asked to press the same two response keys for both tasks, bivalent stimuli can afford either a compatible response (e.g., a right key press for both the color and case decisions) or an incompatible response (e.g., a right key press for the color decision but a left key press for the case decision). Thus, while compatible bivalent stimuli involve a task conflict only, incompatible bivalent stimuli involve both a task and a *response* conflict. Typically, performance is slower for incompatible bivalent stimuli than for compatible bivalent stimuli, which, in turn, is slower than for univalent stimuli (i.e., stimuli with relevant features for one task). This pattern of results shows that more conflict triggers a larger cost on the conflict-loaded trial. However, it remains unknown whether this larger cost persists across subsequent trials.

The purpose of the present study was to determine whether more conflict triggers more adjustment of cognitive control for subsequent performance. This question is particularly important in order to assess the original view of Botvinick et al. (2001) according to which the adjustment of cognitive control following a conflict is not affected by the characteristics of this conflict. We focussed on the adjustment of cognitive control following bivalent stimuli, which has been coined the bivalency effect (Meier, Woodward, Rey-Mermet, & Graf, 2009; Woodward et al., 2003; Woodward, Metzak, Meier, & Holroyd, 2008; see Meier & Rey-Mermet, 2012a, for a review). The paradigm typically used to investigate the bivalency effect involves three blocks with regular switches between a parity decision (odd vs. even), a color decision (red vs. blue), and a case decision (uppercase vs. lowercase; see Fig. 1). In the first and third blocks (the pure blocks), all stimuli are univalent (i.e., black numerals for the parity decision, colored symbols for the color decision, and black letters for the case decision). In the second block (the mixed block), some letters for the case decisions appear in red or blue color, which turn them into bivalent stimuli. The bivalency effect is the slowing occurring on all univalent trials following bivalent stimuli, including those sharing no relevant features with bivalent stimuli (i.e., the parity-decision trials).

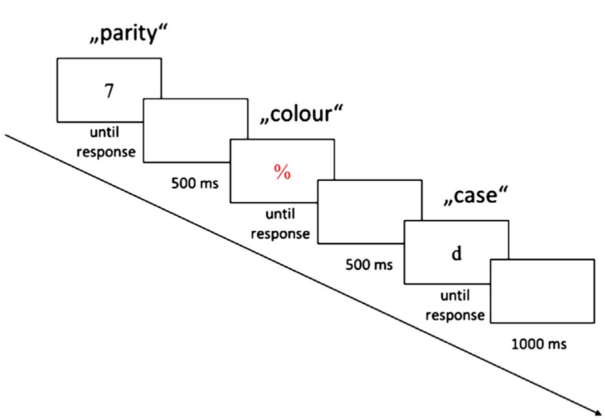

Fig. 1. Example of one univalent task triplet. Participants carried out a parity decision (odd vs. even) on numerals, a color decision (red vs. blue) on symbols, and a case decision (upper- vs. lowercase) on letters. They pressed the key *b* to respond "even", "red", and "uppercase", and the key *n* to respond "odd", "blue", and "lowercase". On a bivalent task triplet (not pictured here), the letters were presented in either blue or red.

In two experiments, we tested whether the magnitude of the bivalency effect was similar after compatible and incompatible bivalent stimuli. In Experiment 1, half of bivalent stimuli were compatible, and the other half incompatible. In Experiment 2, bivalent stimuli were compatible for half of the participants and incompatible for the other half.

We hypothesized that if the characteristics of the conflict affect the adjustment of cognitive control (see Egner, 2008; Yeung et al., 2004, 2011), more conflict would trigger more adjustment of cognitive control for the subsequent trials. In this case, the bivalency effect would be larger after incompatible than after compatible bivalent stimuli. In contrast, if only the occurrence of a conflict, but not its characteristics, affects the adjustment of cognitive control (Botvinick et al., 2001), we would not expect a modification of the bivalency effect.

2. Experiment 1

2.1. Method

2.1.1. Participants

Participants were 20 students (6 men, mean age = 21.6, *SD* = 2) from the University of Bern. The study was approved by the local ethical committee of the University of Bern.

2.1.2. Materials

For the parity decision, the stimuli were the numerals 1 through 8, each displayed in black. For the color decision, the stimuli were the symbols %, #, $, and §, each displayed in either blue or red. For the case decision, the stimuli were the upper- or lowercase consonants d, f, r, t, each displayed in black. We created a set of 16 bivalent stimuli by presenting the same four consonants (d, f, r, t) either in blue or red and either in upper- or lowercase. Specifically, red lowercase and blue uppercase letters were compatible bivalent stimuli, while red uppercase and blue lowercase letters were incompatible bivalent stimuli. All stimuli were presented at the center of the computer screen in 60-point Times New Roman font (cf. Rey-Mermet & Meier, 2012a).

2.1.3. Procedure

Participants were tested individually. They were informed that the experiment involved three different tasks: parity decisions about numerals, color decisions about symbols, and case decisions about letters. They were instructed to press one of two computer keys (*b* and *n*) with their left and right index fingers respectively, for each of the three tasks. The mapping information, printed on paper, was presented below the computer screen throughout the experiment. Participants were informed that, for some of the case decisions, the letters would be presented in either blue or red. They were specifically instructed to ignore color information and to focus on making letter decisions.

After these instructions, a block of 30 task triplets was presented for practice. Each task triplet required making a parity decision, a color decision, and a case decision, always in the same order, as illustrated in Fig. 1. The stimulus for each trial was determined randomly and was displayed until the participant responded. Then, the screen blanked for 500 ms and then the next stimulus appeared. After each task triplet, an additional blank interval of 500 ms was included. After the practice block and a brief break, each participant completed three experimental blocks without break between blocks. The first block included 32 task triplets, with the first two task triplets serving as "warm-up" triplets which were discarded from the analyses. The second and third blocks had 30 task triplets each.

For the first and third block (the pure blocks), only univalent stimuli were presented. For the second block (the mixed block), stimuli were univalent except on 20% of the case decisions in which bivalent stimuli (i.e., red or blue letters) appeared. Half of bivalent stimuli were compatible, the other half incompatible. The particular bivalent stimulus was determined randomly. Task triplets with bivalent stimuli were evenly interspersed among the 30 task triplets of the block; occurring in every fifth task triplet, specifically in the 3rd, 8th, 13th, 18th, 23rd, and 28th triplets. The entire experiment lasted about 15 min.

2.1.4. Data analysis

For each participant, the accuracy rates and the median reaction times (RTs) for correct responses were computed for each task and each block. For the mixed block, we separately computed the accuracy rates and median RTs for compatible and incompatible bivalent case decisions as well as for the univalent stimuli following compatible and incompatible bivalent stimuli. To account for general training effects, we averaged the data from the pure blocks 1 and 3 for each task and each participant.

An alpha level of 0.05 was used for all statistical tests. Greenhouse–Geisser corrections were reported where appropriate and effect sizes were expressed as partial η^2 values. A sensitivity analysis showed that given our sample size and with a power of $1 - \beta = 0.80$ and an α level of 0.05, a medium effect size ($d = .58$) can be detected in Experiment 1 (Faul, Erdfelder, Lang, & Buchner, 2007; Mayr, Erdfelder, Buchner, & Faul, 2007).

2.2. Results

2.2.1. Cost of bivalent stimuli

We first assessed whether performance on bivalent stimuli was worse than performance on the corresponding univalent stimuli (i.e., the black letters from the mixed block) and whether this cost was larger for incompatible than for compatible bivalent stimuli (Rogers & Monsell, 1995; Steinhauser & Hübner, 2007, 2009). Fig. 2A (left panel) depicts the cost of bivalent stimuli.

A one-way repeated-measures analysis of variance (ANOVA) on the RTs with the factor stimulus valence (univalent, compatible bivalent, incompatible bivalent) revealed a significant main effect of stimulus valence, $F(2, 38) = 7.70$, $p < .01$, $\eta^2 = .29$. Thus, performance was slower on incompatible and compatible bivalent stimuli ($M = 1065$ ms, $SE = 125$ and $M = 883$, $SE = 96$, respectively) than on the corresponding univalent stimuli ($M = 720$ ms, $SE = 43$, with $t(19) = 3.61$, $p < .01$, and $t(19) = 2.36$, $p < .05$, respectively). Moreover, the slowing for incompatible bivalent stimuli was considerably larger than the slowing for compatible bivalent stimuli, $t(19) = 1.88$, $p < .05$, one-tailed (see Fig. 2A, left panel).

We also conducted a one-way repeated-measures ANOVA on the accuracy, with the factor stimulus valence (univalent, compatible bivalent, incompatible bivalent). The ANOVA showed no effect, $F(1.26, 23.95) = 2.69$, $p = .11$, $\eta^2 = .12$. Thus, although accuracy was numerically lower for the incompatible bivalent stimuli ($M = .90$, $SE = 0.04$) than for the compatible bivalent stimuli and the corresponding univalent stimuli ($M = .98$, $SE = 0.02$ and $M = .97$, $SE = 0.01$, respectively), this cost was not statistically significant.

2.2.2. Bivalency effect

Our main objective was to examine whether compatible and incompatible bivalent stimuli triggered a similar bivalency effect (i.e., a performance slowing for all tasks following bivalent stimuli). The most relevant results are the RTs from the univalent trials in the pure block compared to those in the mixed block following compatible and incompatible bivalent stimuli. These results are summarized in Table 1 and depicted in Fig. 2A (right panel).

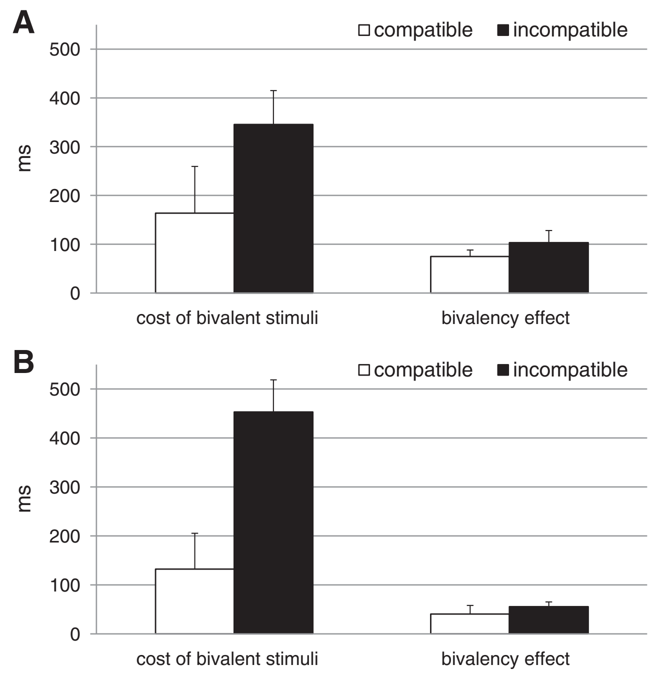

Fig. 2. Cost of bivalent stimuli (i.e., reaction time difference between the bivalent stimuli and the corresponding univalent stimuli, that is, the black letters from the mixed block), and bivalency effect (i.e., reaction time difference between univalent trials from the pure block and those from the mixed block). A) Experiment 1. B) Experiment 2.

A two-way repeated-measures ANOVA with block (pure, mixed after compatible, mixed after incompatible) and task (parity, color, case) revealed a significant main effect of block, $F(1.46, 27.70) = 12.44$, $p < .001$, $\eta^2 = .40$. The main effect of task approached significance, $F(1.36, 25.79) = 3.05$, $p = .08$, $\eta^2 = .14$. The two-way interaction was, however, not significant, $F(4, 76) = 0.33$, $p = .86$, $\eta^2 = .02$. Thus, performance was slowed on all univalent trials after compatible bivalent stimuli, $t(19) = 5.58$, $p < .001$. Similarly, it was also slowed after incompatible bivalent stimuli, $t(19) = 4.18$, $p < .01$. Consequently, a bivalency effect was present after compatible and incompatible bivalent stimuli. Critically, however, the magnitude of the bivalency effects did not differ, $t(19) = 1.19$, $p = .25$ (see Fig. 2A, right panel).

We also conducted a two-way repeated-measures ANOVA on the accuracy of univalent trials, with the factors block (pure, mixed after compatible, mixed after incompatible) and task (parity, color, case). The ANOVA only showed a significant main effect of task, $F(2, 38) = 5.34$, $p < .01$, $\eta^2 = .22$. No other main effects or interactions were significant, $Fs < 1$, $ps > .05$, $\eta^2 < .05$. Thus, performance was higher for the parity and case decisions ($M = .97$, $SE = 0.01$ and $M = .98$, $SE = 0.01$, respectively) than for the color decisions ($M = .95$, $SE = 0.01$). These results indicate that no speed-accuracy trade-off compromised the critical RT effects.

Table 1
Experiment 1: Mean reaction times (in ms) on univalent trials for pure blocks (average of blocks 1 and 3) and the mixed block (block 2). Standard errors in parentheses.

Task	Pure	Mixed after compatible	Mixed after incompatible
Parity	715 (37)	800 (53)	824 (57)
Color	672 (34)	754 (30)	791 (48)
Case	649 (35)	707 (38)	731 (49)
Total	679 (31)	754 (34)	782 (44)

2.3. Discussion

In Experiment 1, we investigated whether the magnitude of the bivalency effect was similar after compatible and incompatible bivalent stimuli. The results demonstrated that performance was slower for bivalent than for univalent stimuli and that this cost was considerably larger for incompatible than for compatible bivalent stimuli. This replicates the previous findings on the conflict-loaded trial (Rogers & Monsell, 1995; Steinhauser & Hübner, 2007, 2009; see also Yeung et al., 2004, 2011). Moreover, the results showed a performance slowing on univalent trials after bivalent stimuli, replicating the bivalency effect (Grundy et al., 2013; Meier & Rey-Mermet, 2012a; Meier, Rey-Mermet, Woodward, Müri, & Gutbrod, 2013; Meier et al., 2009; Metzak, Meier, Graf, & Woodward, 2013; Rey-Mermet, Koenig, & Meier, 2013; Rey-Mermet & Meier, 2012a, 2012b, 2013; Woodward et al., 2003, 2008). Critically, the magnitude of the bivalency effect was similar after compatible and incompatible bivalent stimuli. Therefore, the results of Experiment 1 suggest a dissociation between performance on the conflict-loaded trial and performance after the conflict-loaded trial. More conflict slows responding to the conflict-loaded trial; however, it does not slow further performance.

In Experiment 1, compatible and incompatible bivalent stimuli were intermixed for each participant. Therefore, one might argue that the bivalency effect after compatible bivalent stimuli results from a carry-over of the bivalency effect after incompatible bivalent stimuli. To exclude this possibility, we run a second experiment, in which the compatibility of bivalent stimuli was manipulated between participants. That is, bivalent stimuli were compatible for half of participants and incompatible for the other half. With this change, we were able to make sure that in Experiment 2 any bivalency effect after compatible bivalent stimuli is not caused by incompatible bivalent stimuli.

3. Experiment 2

3.1. Method

3.1.1. Participants

The participants were 40 different students (18 men, mean age = 21.2, *SD* = 3.9) from the University of Bern. Half of them were pseudorandomly assigned to the condition with compatible bivalent stimuli and the other half to the condition with incompatible bivalent stimuli.

3.1.2. Materials

The materials were identical to those of Experiment 1.

3.1.3. Procedure

The procedure was similar to that of Experiment 1 except that for half of participants, bivalent stimuli were compatible; for the other half, they were incompatible.

3.1.4. Data analysis

The data analysis was identical to that of Experiment 1. The sensitivity analysis showed that given our sample size and with a power of $1 - \beta = 0.80$ and an α level of 0.05, a large effect size (d = .80) can be detected in Experiment 2 (Faul et al., 2007; Mayr et al., 2007).

3.2. Results

3.2.1. Cost of bivalent stimuli

As in Experiment 1, we first assessed the cost of bivalent stimuli. To this end, we conducted a two-way ANOVA on the RTs with stimulus valence (univalent, bivalent) as a within-subject factor and bivalent stimuli compatibility (compatible, incompatible) as a between-subjects factor. The ANOVA revealed a significant main effect of stimulus valence, $F(1, 38) = 35.43$, $p < .001$, $\eta^2 = .48$, and of bivalent stimuli compatibility, $F(1, 38) = 6.59$, $p < .05$, $\eta^2 = .15$. Critically, the two-way interaction was significant, $F(1, 38) = 10.66$, $p < .01$, $\eta^2 = .22$. Thus, performance was slower for incompatible bivalent stimuli ($M = 1167$ ms, $SE = 93$) than for the corresponding univalent stimuli ($M = 713$ ms, $SE = 37$, with $t(19) = 6.92$, $p < .001$). Similarly, performance was slower for compatible bivalent stimuli ($M = 795$ ms, $SE = 78$) than for the corresponding univalent stimuli ($M = 662$ ms, $SE = 49$, with $t(19) = 1.80$, $p < .05$, one-tailed). However, the performance slowing was considerably larger for the incompatible bivalent stimuli than for the compatible bivalent stimuli (see Fig. 2B, left panel).

We also conducted a two-way ANOVA on the accuracy, with stimulus valence (univalent, bivalent) as a within-subject factor and bivalent stimuli compatibility (compatible, incompatible) as a between-subjects factor. The ANOVA showed a significant main effect of stimulus valence, $F(1, 38) = 17.26$, $p < .001$, $\eta^2 = .31$, and of bivalent stimuli compatibility, $F(1, 38) = 12.50$, $p < .01$, $\eta^2 = .25$, as well as a significant two-way interaction, $F(1, 38) = 20.33$, $p < .001$, $\eta^2 = .35$. Thus, accuracy was significantly lower for the incompatible bivalent stimuli ($M = .85$, $SE = 0.03$) than for the corresponding univalent stimuli ($M = .98$, $SE = 0.01$, with $t(19) = 4.96$, $p < .001$). In contrast, accuracy was similar for the compatible bivalent stimuli ($M = .98$, $SE = 0.01$) and the corresponding univalent stimuli ($M = .98$, $SE = 0.01$, with $t(19) = -0.36$, $p = .72$).

3.2.2. Bivalency effect

Table 2 shows the means of the median RTs on univalent trials with the associated standard errors. Fig. 2B (right panel) depicts the bivalency effect. To examine the bivalency effect after compatible and incompatible bivalent stimuli, we carried a three-way ANOVA with block (pure, mixed) and task (parity, color, case) as within-subject factors and bivalent stimuli compatibility (compatible, incompatible) as a between-subjects factor. The ANOVA revealed a significant main effect of block, $F(1, 38) = 23.03$, $p < .001$, $\eta^2 = .38$. This was caused by slower responses on univalent trials in the mixed block ($M = 759$ ms, $SE = 21$) than in the pure block ($M = 711$ ms, $SE = 20$), which confirms the presence of the bivalency effect. The ANOVA also showed a significant main effect of task, $F(2, 76) = 14.03$, $p < .001$, $\eta^2 = .27$. Most critically, neither the two-way interaction between block and bivalent stimuli compatibility nor the three-way interaction between block, task, and bivalent stimuli compatibility was significant, $F(1, 38) = 0.55$, $p = .46$, $\eta^2 = .01$ and $F(1.72, 65.52) = 0.92$, $p = .39$, $\eta^2 = .02$, respectively (observed power for the null effect of both interactions was 0.11 and 0.19). Furthermore, no other main effects or interactions were significant, $Fs < 2.99$, $ps > .05$, $\eta^2 < .07$. Thus, as depicted in Fig. 2B, the bivalency effect was similar after compatible and incompatible bivalent stimuli.

We also conducted a three-way ANOVA on the accuracy of univalent trials, with block (pure, mixed) and task (parity, color, case) as within-subject factors and bivalent stimuli compatibility (compatible, incompatible) as a between-subjects factor. The ANOVA only showed a significant main effect of task, $F(2, 76) = 3.74$, $p < .05$, $\eta^2 = .09$. No other main effects or interactions were significant, $Fs < 1$, $ps > .05$, $\eta^2 < .02$. Thus, accuracy was higher for the parity and case decisions ($M = .97$, $SE = 0.005$ and $M = .98$, $SE = 0.01$, respectively) than for the color decisions ($M = .96$, $SE = 0.01$). These results indicate that no speed-accuracy trade-off compromised the critical RT effects.

Table 2
Experiment 2: Mean reaction times (in ms) on univalent trials for pure blocks (average of blocks 1 and 3) and the mixed block (block 2). Standard errors in parentheses.

Task	Compatible		Incompatible	
	Pure	Mixed	Pure	Mixed
Parity	735 (25)	761 (28)	745 (34)	767 (31)
Color	731 (45)	782 (35)	769 (33)	867 (43)
Case	617 (32)	662 (49)	667 (35)	713 (37)
Total	695 (28)	735 (30)	727 (30)	783 (30)

3.3. Discussion

The results of Experiment 2 replicated those of Experiment 1. They showed a larger cost on incompatible than on compatible bivalent stimuli and they demonstrated a reliable bivalency effect. Moreover, the magnitude of the bivalency effect was again similar after compatible and incompatible bivalent stimuli. Even when only compatible bivalent stimuli were presented, a bivalency effect occurred in a similar magnitude as when only incompatible bivalent stimuli were presented. This excludes the possibility that a carry-over effect was responsible for the results in Experiment 1. Rather, Experiment 2 replicates and extends the finding that more conflict does not lead to more adjustment of control for subsequent performance.

4. General discussion

The purpose of the present study was to investigate whether more conflict triggers more adjustment of cognitive control for subsequent performance. To this end, we tested whether incompatible bivalent stimuli trigger a larger bivalency effect than compatible bivalent stimuli. The results demonstrated a performance slowing on univalent trials after bivalent stimuli, replicating the bivalency effect (Grundy & Shedden, 2013; Grundy et al., 2013; Meier & Rey-Mermet, 2012a; Meier et al., 2009, 2013; Metzak et al., 2013; Rey-Mermet & Meier, 2012a, 2012b, 2013; Rey-Mermet et al., 2013; Woodward et al., 2003, 2008). Critically, the magnitude of the bivalency effect was similar after compatible and incompatible bivalent stimuli, both in a within-subject design (Experiment 1) and in a between-subjects design (Experiment 2). On the conflict-loaded trial, the present results replicate previous findings by showing that the cost of bivalent stimuli was larger for incompatible than for compatible bivalent stimuli (Rogers & Monsell, 1995; Steinhauser & Hübner, 2007, 2009; see also Yeung et al., 2004, 2011).

These results indicate that more conflict in bivalent stimuli triggers a larger cost for the conflict-loaded trial, but not a larger bivalency effect. As the conflict-loaded trial involved the detection of a conflict as well as the adjustment of cognitive control to resolve the conflict (Botvinick et al., 2001), one might assume that a larger cost on the conflict-loaded trial results from an additional detection of conflict, an additional adjustment of cognitive control or both. However, as the trials following the conflict involved only the adjustment of cognitive control and this adjustment of cognitive control remained similar even with more conflict, our results suggest that the larger cost on the conflict-loaded trial results from the additional detection of conflict (Rogers & Monsell, 1995; Steinhauser & Hübner, 2007, 2009; Yeung et al., 2004, 2011).

We would like to emphasize that in the present study, the manipulation of the amount of conflict involved two different types of conflicts. Compatible bivalent stimuli involved a task conflict only while incompatible bivalent stimuli induced both a task and a response conflict. Thus, the results of the present study showed that encountering a response conflict in addition to the task conflict did not affect the bivalency effect. However, it remains unclear whether manipulating specifically the amount of *task* conflict in bivalent stimuli would also affect the bivalency effect. Further research might address this issue by simulating the amount of task conflict and the resulting bivalency effect (cf. Yeung et al., 2004, 2011).

We would also like to mention that – in line with all the previous studies on the bivalency effect (Grundy & Shedden, 2013; Grundy et al., 2013; Meier et al., 2009, 2013; Metzak et al., 2013; Rey-Mermet & Meier, 2012a, 2012b, 2013; Rey-Mermet et al., 2013; Woodward et al., 2003, 2008) – we have opted for a fixed task order in both experiments such that each task was predictable. Thus, participants may have anticipated the upcoming task, which may have affected the results. However, it is unlikely that the order of tasks interacted with the presence of compatible and incompatible bivalent stimuli because the impact of task order was eliminated by calculating the bivalency effect as the difference between the univalent stimuli of the mixed block and the pure block. However, the predictability of tasks leaves open the possibility that participants may have anticipated the occurrence of the next bivalent stimulus in the case decision. This question is important and relates to the distinction between proactive control and retroactive control (Braver, 2012; Braver, Gray, & Burgess, 2007).

Proactive control reflects the sustained and anticipatory maintenance of task-relevant representations and is initiated before a conflict is encountered. In contrast, reactive control reflects the transient stimulus-driven reactivation of task representations after a conflict was encountered. The bivalency effect clearly contains a reactive component because it follows the conflict induced by bivalent stimuli. However, due to the possible predictability of tasks and thus of bivalent stimuli, it may also reflect a proactive control process in anticipation of the occurrence of the next bivalent stimulus. In a recent study, we have tested this possibility using a similar set-up as the present study, but in order to induce proactive control, we asked participants to deliberately search for bivalent stimuli (Meier & Rey-Mermet, 2012b). Participants were instructed to respond with a different key-press (i.e., the "h" key) whenever they noticed a bivalent stimulus. The results showed that inducing proactive control did not result in the same pattern of slowing as the bivalency effect. Thus, the predictability of tasks and of bivalent stimuli did not seem to affect the bivalency effect in the present study.

More generally, the findings of the present study extend previous studies of the bivalency effect. These studies have shown that the bivalency effect occurs with different types of tasks, different types of bivalent stimuli, across different modalities, and with overlapping as well as with non-overlapping response sets (Meier et al., 2009; Rey-Mermet & Meier, 2012a). It was found to persist across at least 12 decisions with univalent stimuli, that is, for more than 20 s (Meier et al., 2009). The bivalency effect is associated with activation in the dorsal anterior cingulate cortex, a brain area recruited for the adjustment of cognitive control (Grundy et al., 2013; Woodward et al., 2008). It is also associated with an event-related potentials component reflecting interference (Rey-Mermet et al., 2013). Moreover, a neuropsychological study revealed the lack of bivalency effect by amnesic patients who have profound problems with binding episodes to the context in which they occur (Meier et al., 2013). Based on these findings, we have recently put forward an "episodic context binding" account to explain the bivalency effect (Meier & Rey-Mermet, 2012a; Meier et al., 2009). As amnesic patients showed no bivalency effect, it is likely that this effect results, at least in part, from episodic binding (see Meier et al., 2013). However, as the bivalency effect occurs irrespective of stimulus, response or task-set overlap (Rey-Mermet & Meier, 2012a; Woodward et al., 2003), this binding must go beyond stimulus, response and task features, and thus extend to the particular context. That is, the stimulus and the task are bound to the context in which they occur. In the particular paradigm used to assess the bivalency effect, the context consists of the whole task triplet that typically involves univalent stimuli. The univalent stimuli and tasks are bound to this context, which is updated on subsequent task triplets. The occurrence of a bivalent stimulus makes the context more demanding. On subsequent task triplets, the representation of the – now conflict-loaded – context is re-activated and interferes with processing the univalent trials (Rey-Mermet et al., 2013). This slows down performance and results in the bivalency effect. According to this account, the bivalency effect reflects an adjustment of cognitive control which suppresses the interference caused by the reactivation of the more demanding context created by bivalent stimuli in order to process the tasks with purely univalent stimuli. The present results are compatible with this account. They suggest that the more demanding context is created similarly by a compatible or an incompatible bivalent stimulus.

The present results also replicate the similar magnitude of the bivalency effect for the subsequent univalent trials, which involved one or two types of conflict (Meier et al., 2009; Rey-Mermet & Meier, 2012a, 2012b; Woodward et al., 2003). In those studies, the amount of conflict on *subsequent* trials varied as in the present study, however, without consideration of the amount of conflict in the conflict-triggering stimuli (i.e., the bivalent stimuli). For example, one type of conflict is the necessity to switch between tasks. As task switching requires the inhibition of the previous task and the activation of the new task, it inherently involves a conflict (e.g., Allport & Wylie, 2000; Rogers & Monsell, 1995). This type of conflict is present in all univalent trials. The second type of conflict is the overlap of stimulus features in subsequent univalent stimuli due to the previous presence of bivalent stimuli (e.g., Allport & Wylie, 2000; Meiran, 2008; Waszak, Hommel, & Allport, 2003). This type of conflict is only present in those univalent trials that share relevant features with the bivalent stimuli. Importantly, the magnitude of the bivalency effect is typically similar for the univalent trials sharing no relevant features with bivalent stimuli, that is, those trials with one conflict (task switching), and for the univalent trials sharing relevant features with bivalent stimuli, that is, those trials with two conflicts (task switching and priming of bivalent stimulus features; Meier et al., 2009; Rey-Mermet & Meier, 2012a, 2012b; Woodward et al., 2003). However, the magnitude of the bivalency effect is reduced for those univalent trials without conflict (i.e., repetition trials sharing no relevant features with bivalent stimuli, see Rey-Mermet & Meier, 2012b). Thus, on subsequent univalent trials, the bivalency effect is sensitive to the presence of conflict, but not to its amount.

Together, the previous and present results indicate that the bivalency effect is not sensitive to the amount of conflict of subsequent univalent trials and of the conflict-triggering stimuli (i.e., the bivalent stimuli). Therefore, the adjustment of cognitive control underlying the bivalency effect is only sensitive to the occurrence of conflict. This suggests that the type of information conveyed by the adjustment of cognitive control following bivalent stimuli is very unspecified, as originally proposed by Botvinick et al. (2001).

5. Conclusion

In sum, the previous and the present results suggest that as long as a conflict is present in both the conflict-triggering stimuli and the subsequent trials, a bivalency effect of similar magnitude occurs. This indicates that the occurrence of a conflict is necessary to trigger cognitive control, but the subsequent adjustment of control is not sensitive to the amount of this conflict. More generally, it seems that *more* conflict does *not* necessarily trigger more adjustment of cognitive control for subsequent events.

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