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RESEARCH ARTICLE

Smaller backward crosstalk effects for free choice tasks are not the result of immediate conflict adaptation

Christoph Naefgen[1] · **Markus Janczyk**[1]

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Abstract
In dual-task situations, mutual interference phenomena are often observed. One particularly interesting example of such phenomena is that even Task 1 performance is improved if Task 2 requires a compatible (e.g., both responses are given on the left side) instead of an incompatible response (e.g., one response is given on the right side, and the other on the left side). This is called the compatibility-based backward crosstalk effect (BCE). In a previous paper, we observed support for a critical role of stimulus–response (S–R) links in causing this effect: The BCE was smaller when one of the two tasks was a free choice task. However, an alternative explanation for this observation is that free choice tasks lead to immediate conflict adaptation, thereby reducing the interference from the other task. In the present two experiments, we tested this explanation by varying the amount of conflict assumed to be induced by a free choice task either sequentially (Exp. 1) or block-wise (Exp. 2). While we replicated a sequential modulation of the BCE with two forced choice tasks, we observed (1) no reduction of the BCE induced by (compatible) free choice trials nor (2) an effect of block-wise manipulations of the frequency of free choice trials on the size of the BCE. Thus, while the BCE is sensitive to sequential modulations induced by the (in)compatibility of two forced choice responses, which might point to conflict adaptation, the reduced BCE in dual-task situations involving a free choice task is likely due to its weaker S–R links.

Keywords Conflict adaptation · Backward crosstalk effect · Free choice tasks · Dual-task

Introduction

Dual-tasking and the backward crosstalk effect

When humans work on two tasks simultaneously, performance in one or both tasks usually becomes worse. These dual-task costs can be influenced in various ways, depending on the tasks' specific characteristics. In the case that characteristics of Task 2 performance influence even performance in Task 1, this is called a *backward crosstalk effect* (BCE). The example we investigate here is based on spatial compatibility between the responses required in both tasks: If both tasks require spatially compatible responses (e.g., a manual left button press in Task 1 followed by a left pedal button press or a "left" vocal response in Task 2), response times (RTs) in Task 1 are shorter in comparison with trials with spatially incompatible responses (e.g., a manual left button press followed by a right pedal button or a "right" vocal response). This is the compatibility-based BCE, which was first demonstrated by Hommel (1998; see also Ellenbogen and Meiran 2008, 2011; Giammarco et al. 2016; Hommel and Eglau 2002; Janczyk et al. 2014, 2018; Lien and Proctor 2000; Renas et al. 2017; Watter and Logan 2006).

Such observations are difficult to reconcile with the broadly accepted central bottleneck theory of dual-tasking. This theory assumes that task processing comprises three stages: a pre-central perceptual stage, a central response selection stage, and a post-central motor stage. The central response selection stage is conceived as the only stage incapable of parallel processing and interaction with other stages of its kind, hence the term bottleneck (Pashler 1984, 1994). In other words, response selection in Task 2 can only start when response selection in Task 1 has finished and the bottleneck becomes again available. However, the existence of BCEs has challenged this idea. It was argued that some response selection-related processes in Task 2 must already be ongoing even during Task 1 response selection. Thus,

✉ Christoph Naefgen
christoph.naefgen@uni-tuebingen.de

[1] Department of Psychology, Eberhard Karls University of Tübingen, Schleichstraße 4, 72076 Tübingen, Germany

some authors argued to split the response selection stage into two stages: (1) a first stage of *response activation*, capable of being processed in parallel with other stages and interacting with them (and thus being the stage where the BCE results from) and (2) a bottleneck stage of *(final) response selection* (Hommel 1998; Hommel and Eglau 2002; Lien and Proctor 2002). Recently, other authors have argued, however, that automatic Task 2 response activation directly affects Task 1 response selection (Janczyk et al. 2018; Thomson et al. 2015).

In most studies on the BCE, both component tasks were *forced choice tasks*, which means that for every presented stimulus exactly one response is considered correct. A different type of task is the *free choice task*, in which for one stimulus, two (or more) responses are considered equally valid (Berlyne 1957). Typically, these free choice tasks are accompanied by the instruction to try to respond with both responses about equally often and to avoid obvious patterns in the responses. A typical observation is that RTs are longer in free choice tasks than in forced choice tasks. There are multiple explanations for this observation: Some have attributed it to different modes of sensorimotor integration (i.e., intention-based vs. stimulus-based actions; see Herwig et al. 2007). Others have ascribed this RT difference to implementation intentions (Gollwitzer 1999) that do not exist for free choice tasks, but only for forced choice tasks (Janczyk et al. 2015a). Implementation intention here means that participants form an "if–then" plan on how to achieve the goal in question. In the case of forced choice tasks, this may, for example, be "If I see a red stimulus, I press the left button." Such plans are assumed to facilitate early perceptual processing for forced choice stimuli, resulting in the observed RT difference. Naefgen et al. (2017b) looked at the RT difference from a sequential sampling perspective. In such a framework, information is noisily accumulated at some speed over time until it reaches a threshold, which initiates giving a response. Within this framework, they manipulated the decision thresholds and provided evidence for longer phases in which no information is accumulated in free choice tasks when compared to forced choice tasks, which may be devoted to random generation in the free choice task (Naefgen and Janczyk 2018). Moreover, in line with these latter studies that attribute the RT difference to a process outside response selection, both free and forced choice tasks are similarly affected by dual-task interference (Janczyk et al. 2015b).

In a recent study, we compared the size of the BCE between conditions in which one of the two tasks was either a free choice task or a forced choice task (Naefgen et al. 2017a). We assumed that free choice tasks entail weaker stimulus–response (S–R) links than forced choice tasks do. Even if in free choice tasks S–R links are formed, they would be less consistent and therefore weaker than in forced choice tasks. S–R links (or more precisely: automatic S–R translations occurring in Task 2) have been proposed as the mechanism leading to the BCE by various authors (Hommel 1998; Hommel and Eglau 2002; Janczyk et al. 2018; Lien and Proctor 2002). The general observation in the study by Naefgen et al. was a smaller BCE when one of the tasks was a free choice task—a result that would be consistent with the assumption of weaker S–R links in the free choice task.

Cognitive conflict and control

Berlyne (1957) already conceptualized free choice tasks as response–response (R–R) conflict-laden tasks. Essentially, whenever a free choice stimulus is presented, the (two) response options compete with each other. In order to produce a response, some sort of conflict resolution needs to take place. This view suggests an alternative explanation for our earlier observation of a smaller BCE with free choice tasks as Task 1 (see also General Discussion in Naefgen et al. 2017a). In particular, the smaller BCE may in fact also result from conflict adaptation. In other words, encountering a free choice task may result in (cognitive) conflict which then leads to immediate processes of conflict adaptation which reduce the impact of Task 2 on Task 1 performance.

Botvinick et al.'s (2001) conflict-monitoring theory posits that cognitive control is determined by conflict monitoring and arises whenever conflict is detected. In particular, it suggests that conflict arises and leads to increases in cognitive control mechanisms in conflict tasks (e.g., Stroop tasks), but also in underdetermined tasks (e.g., such as the free choice task investigated here; cf. Exp. 2 from Frith et al. 1991, who used a similar task and observed that it activates the anterior cingulate cortex, which Botvinick et al. identified as involved in cognitive control). These mechanisms can, for example, be an increased focus on task-relevant features (Botvinick et al. 2001) or a suppression of task-irrelevant information (Janczyk and Leuthold 2018; Stürmer and Leuthold 2003; Stürmer et al. 2002).

One particularly important effect in support of this theory is the sequential modulation of the congruency effect observed in conflict tasks. For example, in the Eriksen flanker task (Eriksen and Eriksen 1974), a central stimulus is flanked by task-irrelevant stimuli that are either congruent (i.e., they suggest the same response option as the central stimulus) or incongruent (i.e., they suggest the other response option). Responses to congruently flanked stimuli are generally faster than responses to incongruently flanked stimuli (the congruency effect). Importantly, the size of this congruency effect depends on the congruency status of the preceding Trial $n-1$ with larger congruency effects following congruent than following incongruent Trials $n-1$; a sequential modulation sometimes referred to as the Gratton effect (Gratton et al. 1992). Similar results are also obtained for other conflict tasks (Simon task: Akçay and Hazeltine 2007; Dignath et al. 2017; Stroop: Mayr and Awh 2009; Notebaert et al. 2006) and also occur for the BCE which is only observed following compatible Trials $n-1$ (Janczyk 2016; Renas et al. 2017; Scherbaum et al. 2015; see also Schuch et al. 2018). Importantly for the present purposes, it has been shown that adaptation to cognitive conflict can happen even within the course of one trial (Goschke and Dreisbach 2008; Scherbaum et al. 2011). Thus, it is in fact possible that R–R conflict occurring upon encountering a free choice task (Berlyne 1957) could have affected the size of the BCE by way of immediate conflict adaptation in our previous experiments (Naefgen et al. 2017a). For an illustration of how different kinds of conflict (could) affect the size of the BCE, see Fig. 1.

With the present study we aim to address (and rule out) this alternative explanation. To this end, we manipulated the level of conflict in two BCE experiments. In Experiment 1, we manipulated the degree of conflict in a previous dual-task trial, that is, in Trial $n-1$, and focused on the size of the following BCE. In Experiment 2, we manipulated the conflict-level block-wise, by varying the proportion of trials in which the first task was a free choice task.

Experiment 1

Experiment 1 employed a standard BCE paradigm with the simultaneous onset of two stimuli (the color and the identity of a letter, see Fig. 2 for an illustration). Task 1 responses were manual left/right key presses, and Task 2 responses were left/right foot pedal presses. Unbeknown to the participants, trials were presented in pairs of a prime and a test trial. We systematically manipulated the type of Task 1 in the prime trials (free vs. forced choice) and, in case of forced choice Task 1s (50% of the prime trials, 100% of the test trials), the compatibility relation between both responses. Half of the forced choice prime trials preceding each compatible and incompatible test trial were compatible; the other half was incompatible. This experimental setup produced data that are similar in nature to Experiment 1 from Naefgen et al. (2017a). However, presenting the trials in pairs allowed us to achieve roughly equal numbers of trials in the relevant design cells. (Note that for free choice tasks some variance between participants regarding the proportions of compatible and incompatible trials is to be expected.) The critical analyses focused on the size of the BCE in test trials as a function of the nature of the prime trial. The first prediction concerns trials where Task 1 in the prime trial was a forced choice task. Here, we expect to replicate the observation of Janczyk (2016) that the BCE is smaller or absent following incompatible trials and large following compatible trials. The critical comparison is the one between these latter trials and trials where Task 1 in the prime trial was a free choice task and participants responded in a compatible way. If the free choice task in fact induces cognitive conflict that leads to initiation of adaptation processes, we expect a smaller BCE after compatible free choice prime trials than after compatible forced choice prime trials. If, however, differences in the strength of S–R links are important, the

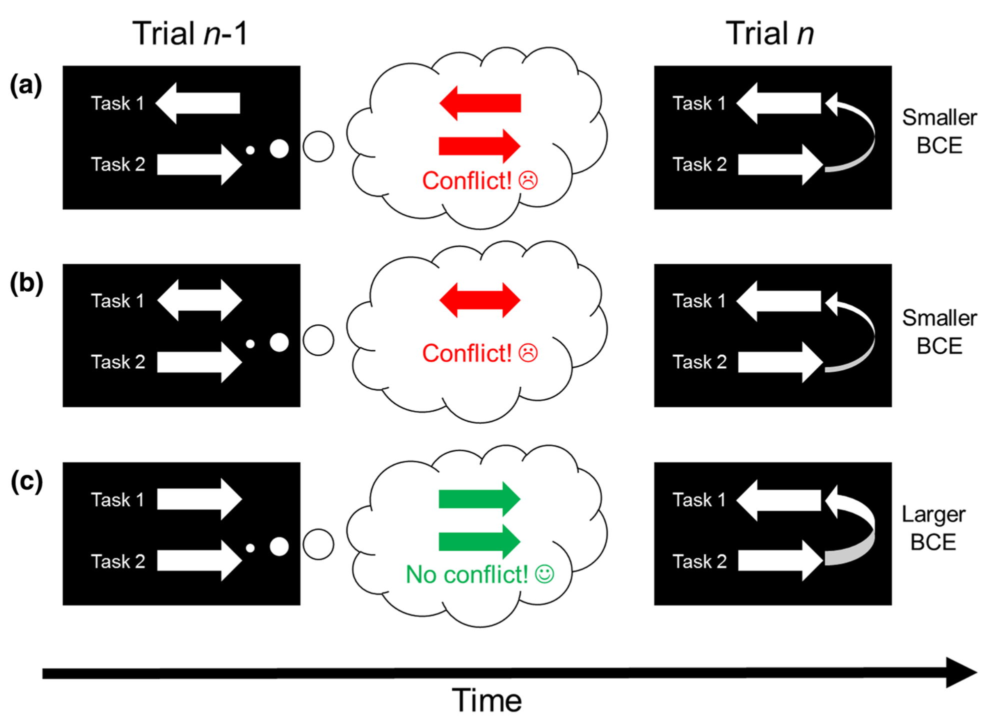

Fig. 1 Illustration of possible different kinds of conflicts in the backward crosstalk paradigm. In the first row **a**, conflict arises from incompatible Task 1 and Task 2 responses. In the second row **b**, conflict arises from the free choice Task 1 (indicated by the double-headed arrow). In the third row **c**, no conflict is present. In cases where conflict occurred in Trial $n-1$, a smaller BCE is expected in Trial n than when there was no conflict present in Trial $n-1$

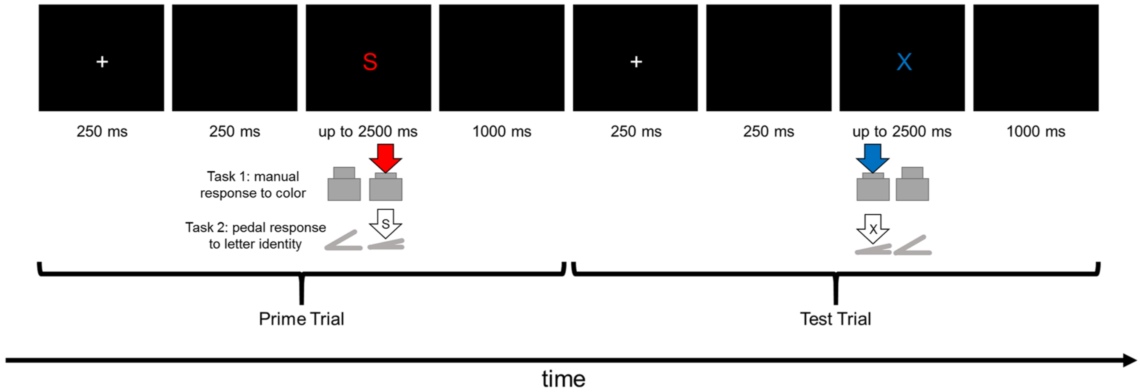

Fig. 2 Illustration of a pair of trials in Experiment 1. The red S is the prime trial stimulus, and the blue X is the test trial stimulus. In this exemplary stimulus mapping, a red stimulus instructs the participant to give a right manual response (prime trial Task 1) and an S stimulus instructs the participants to give a right pedal response (prime trial Task 2). A blue stimulus on the other hand instructs a left response (test trial Task 1) and an X stimulus instructs a left pedal response (test trial Task 2). Therefore, this example illustrates a compatible forced choice test trial (as both responses are on the left side) following a compatible forced choice prime trial (as both responses are on the right side). Note that in Experiment 2 the general procedure was the same, but there was no distinction between prime trials and test trials

size of the BCE in the test trial is expected similar in test trials following compatible forced choice and compatible free choice prime trials. As there were no predictions concerning trials where the prime trials were a free choice and participants responded in an incompatible way, these trials were not included in the main analyses reported here. However, analyses of the full 2 × 2 × 2 design are provided in the Appendix for completeness.

Methods

Participants

Thirty-six people from the Tübingen area participated (mean age = 22 years, 31 female) for course credit or monetary compensation. All participants reported normal or corrected-to-normal vision, were naïve regarding the underlying hypotheses, and provided written informed consent prior to data collection.

Data from participants who favored a left manual response in ≤ 15% or ≥ 85% of the free choice prime trials or whose Task 1 free choice prime trial response were ≤ 15% compatible or ≥ 85% compatible with Task 2 response were discarded and replaced with data from new participants ($n = 11$).

Apparatus and stimuli

Stimulus presentation and response collection were controlled by a PC connected to a 17-inch CRT monitor. Stimuli were colored letters, that is, the letters 'X' and 'S' presented in red, green, or blue color. In particular, Task 1 stimuli (S1) were the respective colors, and Task 2 stimuli (S2) were the letter identities. Stimuli were presented against a black background. Manual responses in Task 1 (R1) were collected with two custom-built response keys placed on a table to the left and right of the participants. Foot pedal responses in Task 2 (R2) were given on response keys placed under the left and right foot of the participants in a position that allowed them to sit in a comfortable position.

Tasks and procedure

Task 1 was either to give a predefined R1 in response to two of the possible colors (forced choice task) or to freely choose one of the possible responses in response to the third color (free choice task). Task 2 was to give R2 in response to the letter identity. (Thus, Task 2 was always forced choice.) A trial began with the presentation of a small fixation cross (250 ms), followed by a blank screen (250 ms) and the letter stimulus onset. The stimulus remained on screen until both responses were made. A trial was canceled if no response was given within 2500 ms after stimulus onset. General errors (no response, response too early, wrong response order) and erroneous responses in one or both tasks were fed back (1000 ms), and the next trial started after an inter-trial interval (ITI) of 1000 ms. Trials were (without the participants' knowledge) presented in pairs, with the first trial in each pair being the prime and the second being the test trial. In half of the prime trials, Task 1 was a free choice task, in the other half a forced choice task. In test trials, Task 1 was always forced choice.

Following ten randomly drawn practice trial pairs (not analyzed), nine blocks of 32 trial pairs each were administered; the first two of these blocks were excluded from the analyses as practice. The 32 trial pairs per block represent the combination of the different stimuli that can occur in the prime and the test trial, with the number of free choice stimulus appearances doubled to allow for both left and right responses: 4 (Prime S1: free choice, free choice, forced choice left, and forced choice right) × 2 (Prime S2: forced choice left and right) × 2 (Test S1: forced choice left and right) × 2 (Test S2: forced choice left and right). These trial pairs were presented in a random order.

Participants were tested individually in one single session of about 45 min. Written instructions emphasized speed and accuracy and, for the free choice trials, an even distribution of left and right responses as well as avoiding patterns to maintain this distribution. Participants were also instructed to always give first R1 and then R2. The mappings of stimuli to tasks/responses were counterbalanced across participants.

Design and analyses

Only test trials following entirely correct prime trials were considered for analyses. A trial was considered compatible when both R1 and R2 were given on the same side; otherwise, a trial was incompatible.

Test trials with general errors were excluded first (wrong response, no response, response too early, wrong response order). Further, to control for possible response grouping (e.g., Miller and Ulrich 2008; Ulrich and Miller 2008), only trials were analyzed where both responses were separated by an inter-response interval (IRI) of at least 50 ms (excluding 1.2% of trials; using IRIs of 100 ms and 150 ms changed none of the significance patterns). For RT analyses, we considered only test trials in which both R1 and R2 were correct, and trials were further excluded as outliers if RTs deviated more than 2.5 *SD*s from the respective cell mean (calculated separately for each participant).

The two independent variables of interest were: (1) R1–R2 compatibility in the test trial (compatible vs. incompatible) and (2) the conflict level in the prime trial (forced choice incompatible vs. forced choice compatible vs. free choice compatible). RT and error data were analyzed with two orthogonal Helmert contrasts on the variable conflict level and their interaction with the variable compatibility in the test trial. For the latter we expected a main effect. Contrast 1 coded incompatible forced choice primes against the other two levels, and we expected an interaction of this contrast with test trial compatibility (revealing the sequential modulation observed, e.g., in Janczyk 2016). Contrast 2 then coded compatible forced choice primes against compatible free choice primes. If the free choice prime induced some sort of conflict adaption, this should yield a decreased BCE in the test trial and thus an interaction of this contrast with test trial compatibility. Both RTs and percentages of errors (PEs) in Task 1 were analyzed with this approach. Task 2 results are provided in the Appendix.

Lastly, analyzing the proportion of compatible (Task 1) response choices in prime trials involving a free choice task, gave the opportunity to replicate the observations in Naefgen et al. (2017a, Experiments 1 and 2) that the choice in a free choice task is influenced by the response required in a subsequent forced choice task. In particular, participants' choices were biased toward choosing a compatible response.

Results and discussion

In the free choice tasks, participants chose the left key on average 43.8% of the time (range 18.0–80.7%), which is significantly different from 50%, $t(35) = -2.25$, $p = .031$, $d = -.53$.

Mean correct RTs in Task 1 (2.14% excluded as outliers) are visualized in Fig. 3 and are summarized in Table 1. Responses were faster in compatible trials than in incompatible trials, $t(35) = 6.47$, $p < .001$, showing an overall BCE. Both contrasts were significant, Contrast 1: $t(35) = 5.50$, $p < .001$; Contrast 2: $t(35) = 7.60$, $p < .001$. Most importantly, Contrast 1 interacted with compatibility in the test trial, $t(35) = 10.66$, $p < .001$, whereas Contrast 2 did not, $t(35) = 0.99$, $p = .328$.

Paired *t*-tests indicated significant BCEs for trials preceded by compatible free choice trials (129 ms), $t(35) = 7.24$, $p < .001$, $d = 1.71$, as well as preceded by compatible forced choice trials (146 ms), $t(35) = 10.59$, $p < .001$, $d = 2.50$. When preceded by incompatible forced choice trials, the BCE was reversed (− 59 ms), $t(35) = -3.96$, $p < .001$, $d = -.93$.

Mean PEs are summarized in Table 1. The compatibility in the test trial, $t(35) = 5.28$, $p < .001$, had a significant influence on the PEs with—overall—fewer errors in compatible compared with incompatible trials. As in the RT analyses, Contrast 1, $t(35) = 4.66$, $p < .001$, Contrast 2, $t(35) = 4.28$, $p < .001$, and the interaction of Contrast 1 with compatibility in the test trial, $t(35) = 5.47$, $p < .001$, were significant. The interaction of Contrast 2 and compatibility was not significant, $t(35) = 0.03$, $p = .974$. Paired *t*-tests indicated significant differences in PEs between compatible and incompatible test trials when preceded by compatible free choice primes, $t(35) = 5.57$, $p < .001$, $d = 1.31$, and compatible forced choices primes, $t(35) = 6.13$, $p < .001$, $d = 1.45$, but not for trials preceded by incompatible forced choice primes, $t(35) = -0.97$, $p = .339$, $d = -.23$.

The last analysis focused on prime trials involving a free choice Task 1 (2.86% outliers). In these trials, participants chose the same response location as required in Task 2, thus a compatible choice, in 58.9% of trials. This value is significantly different from 50%, $t(35) = 4.72$, $p < .001$, $d = 1.11$.

In sum, this experiment yields two main results. First, we replicated the smaller (or even inversed) BCE following incompatible trials (Janczyk 2016), thus a sequential

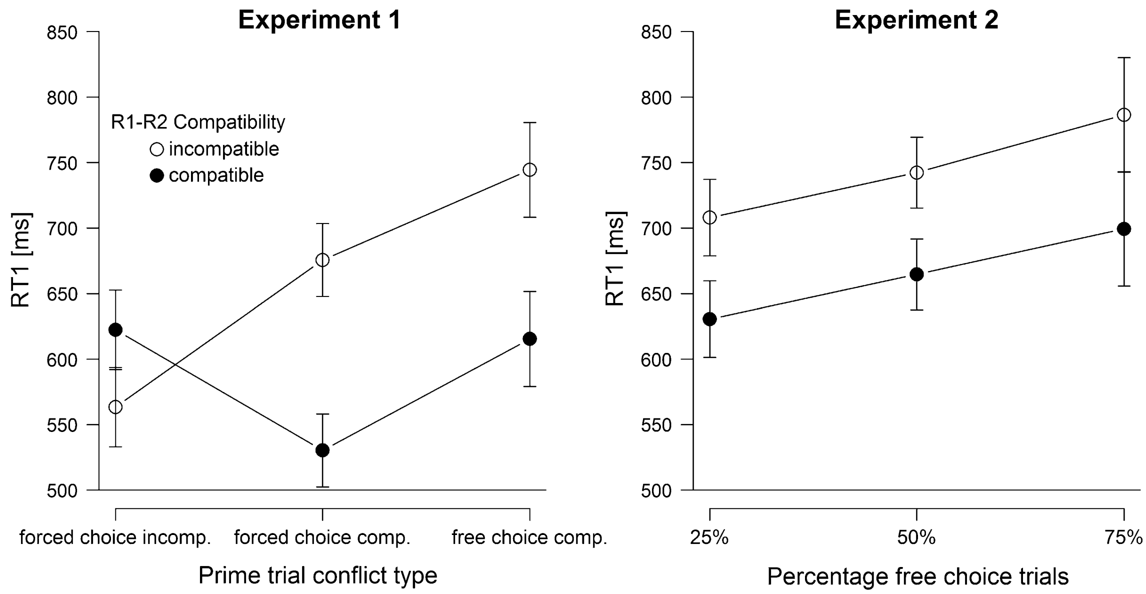

Fig. 3 Mean correct response times from Task 1 (RT1) of Experiments 1 and 2 as a function of prime trial conflict type (Experiment 1) and percentage of free choice trials in a block (Experiment 2) and R1–R2 compatibility. Error bars are 95% within-subject confidence intervals calculated separately for each prime trial conflict type in Experiment 1 and separately for each percentage level of free choice trials in a block in Experiment 2 (see Pfister and Janczyk 2013)

Table 1 Mean correct response times (RT1) in milliseconds and percentages of errors (PE1) from Task 1 of Experiment 1 as a function of prime trial conflict type and R1–R2 compatibility in the test trial

R1–R2 compatibility	Prime trial conflict type					
	Forced choice incompatible		Forced choice compatible		Free choice compatible	
	RT1	PE1	RT1	PE1	RT1	PE1
Incompatible	563	3.7	676	11.3	744	15.2
Compatible	622	5.4	530	1.2	615	5.2
BCE	− 59	− 1.7	146	10.1	129	10.0

The BCE (backward crosstalk effect) row reports the difference between the mean of the compatible and incompatible trials

modulation revealing conflict adaptations. Second, however, the BCE in the test trial was not smaller following a compatible free choice than following a compatible forced choice prime trial. Such a reduction would have been predicted if the smaller BCEs with free choice tasks (Naefgen et al. 2017a) were due to (immediate) conflict adaptations triggered by the free choice task. Thus, from Experiment 1 we tentatively conclude that the diminished BCE observed with free choice tasks in Naefgen et al. did not arise from immediate conflict adaptation processes triggered upon encountering a free choice task. Experiment 2 further investigates this with a different approach.

The choice results for the free choices in prime trials replicate the observations reported in Naefgen et al. (2017a) that the choice in a free choice task is biased by a subsequent Task 2 forced choice response toward a compatible response. This lends additional credibility to the idea discussed there that free choice task choices are biased both by preceding primes (see also Kiesel et al. 2006 and Mattler and Palmer 2012) but also by subsequent ‘primes’ such as the forced choice Task 2 in the present study.

Experiment 2

In addition to the congruency status of the immediately preceding trial, the proportion of congruent trials modulates the size of congruency effects which become larger with an increasing proportion of congruent trials in a block. This observation is called the list-wide proportion congruency (LWPC) effect (Gratton et al. 1992; for a review, see Bugg and Crump 2012). A variant of this effect is the context-specific proportion congruency (CSPC) effect (Crump et al. 2006), where the proportion of congruent trials is manipulated as a function of context (e.g., location), while the overall proportion of congruent and incongruent trials is 50% each. Fischer et al. (2014) reported that the BCE indeed is sensitive to CSPC manipulations (see also Fischer and Dreisbach 2015, who used Task 1 stimuli that conveyed information about the stimulus onset asynchrony and reported a reduced BCE when Task 1 predicted a short SOA). Assuming that the reduced impact of incompatible information under conditions with high proportions of incongruent information is due to an adaptation of how much ‘irrelevant’ information (as this is in part determined by how irrelevant the information actually is) is used (see Botvinick et al. 2001; Schmidt 2013), a similar adaptation to varying proportions of free choice trials should be observed if free choice tasks also induce (R–R) conflict.

Experiment 2 therefore employed the same BCE paradigm as Experiment 1 with the following differences: Trials were no longer presented in pairs. The critical variables manipulated were the proportion of free choice trials in a block (75% vs. 50% vs. or 25%) and the compatibility of R1 and R2. Over the course of a block, participants should adapt to the proportion of free choice trials they are confronted with. In particular, a higher percentage of free choice trials should lead to higher perceived conflict, which in turn should strengthen conflict adaptation. In other words, if the reduced BCE in Naefgen et al. (2017a) was indeed due to R–R conflict-induced conflict adaptation, higher percentages of free choice trials in a block should lead to adaptation to this conflict and thus to smaller BCEs in the trials where both Tasks 1 and 2 were forced choice of the same block.

Methods

Participants

Thirty-six people from the Tübingen area participated (mean age = 23 years, 27 female) for course credit or monetary compensation. All participants reported normal or corrected-to-normal vision, were naïve regarding the underlying hypotheses, and provided written informed consent prior to data collection.

Data from participants who favored a left manual response in ≤ 15% or ≥ 85% of the free choice trials were discarded and replaced with data from new participants ($n = 5$).

Apparatus and stimuli

The apparatus and stimuli were the same as in Experiment 1.

Tasks and procedure

The general procedure was the same as in Experiment 1 except that trials were not presented in pairs. Again, only Task 1 could be free choice. After a practice block of ten trials (excluded from the analysis), three sets of six blocks of 32 trials were presented. Each set of six blocks comprised one of the levels of the free choice frequency manipulation in Task 1 (25% [or 8 per block] vs. 50% [or 16 per block] vs. 75% [or 24 per block]). The order of the three sets of blocks was counterbalanced across participants and trials within each block appeared in a randomized order. The 32 trials in each block result from the combination of even numbers of the types of forced choice trials and the respective percentage of free choice trials.

Participants were tested individually in one single session of about 45 min. Written instructions emphasized speed and accuracy and, for the free choice trials, an even distribution of left and right responses as well as avoiding patterns to maintain this distribution. Participants were also instructed to always give first R1 and then R2. The mappings of stimuli to tasks/responses were counterbalanced across participants.

Design and analyses

Only trials where both Task 1 and Task 2 were forced choice tasks were considered for the main analyses.

Two independent variables were varied within participants: (1) R1–R2 compatibility (compatible vs. incompatible; for forced choice Task 1 trials this could be manipulated by the experimenters) and (2) the amount of free choice Task 1 trials in the block (25% vs. 50% vs. 75%). Accordingly, RTs and PEs from Task 1 were mainly analyzed in terms of a 2 × 3 ANOVA. Trials with general errors were excluded first (wrong response, no response, response too early, wrong response order). Again, only trials were analyzed where both responses were separated by an IRI of at least 50 ms (excluding 1.4% of trials; using IRIs of 100 ms and 150 ms changed none of the significance patterns). For RT analyses, only trials in which both R1 and R2 were correct were considered, and trials were excluded as outliers if RTs deviated more than 2.5 SDs from the respective cell mean (calculated separately for each participant). When the assumption of sphericity was violated, Greenhouse–Geisser corrections were applied and the respective ε is reported. Results for Task 2 are reported in the Appendix.

In addition, the 50% free choice blocks offered an opportunity to replicate the results from Naefgen et al. (2017a), where we observed a smaller BCE when T1 was a free choice task. Accordingly, a 2 × 2 ANOVA with compatibility and task type as repeated measures was performed on RT1 for data from these blocks. As there cannot be errors in a free choice task, PEs in Task 1 were analyzed with a paired *t*-test for Task 1 forced choice trials.

As in Experiment 1, we again took the opportunity to replicate the observations reported in Naefgen et al. (2017a) that the choice in a free choice task is influenced by the required response in a subsequent forced choice task.

Results and discussion

In the free choice tasks, participants chose the left key on average 45.6% of the time (range 20.2–80.7%), which is significantly different from 50%, $t(35) = -2.12$, $p = .041$, $d = -.50$.

Mean correct RT1s (2.43% excluded as outliers) are visualized in Fig. 3 (right panel) and are summarized in Table 2. Responses were faster in compatible trials than in incompatible trials, $F(1,35) = 38.94$, $p < .001$, $\eta_p^2 = .53$, showing an overall BCE. There also was a significant effect of the amount of free choice tasks in a block, $F(2,70) = 7.92$, $p = .001$, $\eta_p^2 = .18$ with more free choice tasks in a block leading to slower responses. Most importantly, there was no significant interaction between compatibility and the amount of free choices, $F(2,70) = 0.17$, $p = .802$, $\eta_p^2 < .01$, $\varepsilon = .83$.

Mean PE1s are summarized in Table 2. Compatibility had a significant effect on PE1s with fewer errors in compatible trials, $F(1,35) = 23.03$, $p < .001$, $\eta_p^2 = .40$. The main effect of the amount of free choices, $F(2,70) = 1.14$, $p = .319$, $\eta_p^2 = .03$, $\varepsilon = .84$, as well as the interaction, $F(2,70) = 0.14$, $p = .830$, $\eta_p^2 < .01$, $\varepsilon = .84$, were not significant.

For the additional analysis on free choice trials (as done by Naefgen et al. 2017a), mean correct RT1s (2.50% excluded as outliers) are summarized in Table 3. Responses were faster in compatible trials than in incompatible trials, $F(1,35) = 20.48$, $p < .001$, $\eta_p^2 = .37$, showing an overall BCE. RT1s in trials with free choices were shorter than in trials with forced choices, $F(1,35) = 38.54$, $p < .001$, $\eta_p^2 = .52$. In addition, there was a significant interaction between these two factors, $F(1,35) = 11.85$, $p = .002$, $\eta_p^2 = .25$, with a smaller BCE in trials with free choices. Paired *t*-tests indicated that there was only a significant BCE for trials with a forced choice Task 1, $t(35) = 5.83$, $p < .001$, $d = 1.37$, but not for trials with a free choice Task 1, $t(35) = 1.21$, $p = .235$, $d = .28$. Fewer errors were made in compatible than in incompatible trials (see Table 3), $t(35) = 4.07$, $p < .001$, $d = 0.96$.

Table 3 Mean correct response times (RT1) in milliseconds and percentages of errors (PE1) from Task 1 of Experiment 2 (50% free choices block) as a function of task type and R1–R2 compatibility

R1–R2 compatibility	Task type		
	Free choice	Forced choice	
	RT1	RT1	PE1
Incompatible	624	742	12.4
Compatible	607	665	4.7
BCE	17	77	7.7

The BCE (backward crosstalk effect) row reports the difference between the mean of the compatible and incompatible trials

When analyzing data from the trials involving a free choice Task 1 (2.50% outliers), participants chose the same response location as in Task 2, thus a compatible choice, in 59.9% of Task 1 free choice trials. This value is significantly different from 50%, $t(35) = 5.23$, $p < .001$, $d = 1.23$. Thus, we could again replicate the respective observations reported in Naefgen et al. (2017a).

In summary, the nonsignificant interaction in the main analysis suggests that the BCE was of the same size irrespective of the amount of free choice trials in a block. In other words, a decreasing size of the BCE with increasing proportions of free choice trials (as predicted from a conflict adaptation account) was not observed. This result further supports the conclusion from Experiment 1. Furthermore, we replicated results reported by Naefgen et al. (2017a) with regard to the reduced BCE when Task 1 is a free choice trial as well as the influence of the forced choice Task 2 on the actual choice that is made in the free choice task. Interestingly, free choice RTs were also shorter than forced choice RTs. This has also been observed in our previous study as well as in other dual-task studies (e.g., Wirth et al. 2018). Note, however, that the opposite was true in the dual-task study by Janczyk et al. (2015).

Table 2 Mean correct response times (RT1) in milliseconds and percentages of errors (PE1) from Task 1 of Experiment 2 as a function of block type and R1–R2 compatibility

R1–R2 compatibility	Block type					
	25% free choices		50% free choices		75% free choices	
	RT1	PE1	RT1	PE1	RT1	PE1
Incompatible	708	11.3	742	12.4	786	13.2
Compatible	630	4.3	664	4.7	699	5.3
BCE	78	7.0	78	7.7	87	7.9

The BCE (backward crosstalk effect) row reports the difference between the mean of the compatible and incompatible trials

General discussion

The present study aimed at testing an alternative explanation for our recent observation that the compatibility-based BCE in dual-tasking is smaller when Task 1 is a free choice task (Naefgen et al. 2017a). We attributed this result to weaker S–R links in free compared with forced choice tasks, but suspected that it may alternatively result from immediate conflict adaptation when participants encountered a free choice Task 1. In two experiments, we examined the size of the BCE depending on the conflict level of the preceding trial (Experiment 1) or the amount of free choice Task 1 trials in a block (Experiment 2). If the alternative explanation were true, we expected smaller BCEs in cases with larger potential conflict.

Summary of results

In both experiments, we first replicated the standard R1–R2 compatibility-based BCE (e.g., Hommel 1998; Janczyk et al. 2018). Second, in Experiment 1 we also replicated the results reported in Janczyk (2016) that the BCE is large in trials following compatible trials and small/absent or even reversed following an incompatible forced choice trial. Third, we were also able to replicate the observation reported in Naefgen et al. (2017a) that the BCE was smaller in free choice Task 1 RTs, but that the actual choices were biased into a compatible direction by the forced choice Task 2 (Experiments 1 and 2). Most importantly, however, we observed no difference in the size of the BCE for trials following compatible free choice and compatible forced choice trials (Experiment 1), and the proportion of free choice trials in a block did not affect the size of the BCE (Experiment 2).

Limitations and theoretical implications

Overall, our results replicated critical aspects of the Naefgen et al. (2017a) study and they offer support for our original conclusion: The smaller BCE in dual-task trials with one of the tasks being a free choice task is likely due to weaker S–R links in this kind of task, rather than by an immediate conflict adaptation upon encountering a free choice trial.

One might object that we did not test for rapid within-trial conflict adaptation in Experiment 1 as described by Scherbaum et al. (2011). Perhaps, conflict adaptation occurs very rapidly and all consequences vanish immediately after the trial. This, however, is implausible as an explanation for the lack of conflict adaptation. While rapid conflict adaptation effects were reported for BCE tasks from mouse tracking experiments, nonetheless a sequential modulation of the BCE in the subsequent trial occurred (Scherbaum et al. 2015). A potential objection to the reasoning behind Experiment 2 is that thus far LWPC effects have not been reported in the context of the BCE. However, Fischer et al. (2014) reported a CSPC modulation of the BCE, arguably even stronger evidence for its susceptibility to LWPC-like manipulations.

The fact that we did not observe any hint of conflict adaptation induced by R–R conflict inherent in free choice tasks has theoretical implications. It is of course possible that free choice tasks do not create R–R conflict as originally assumed by Berlyne (1957). In this case, of course, no conflict adaptation (e.g., in the form of sequential modulations) should occur.

Alternatively, it is possible that free choice tasks elicit R–R conflict and also conflict adaptation but that this conflict adaptation does not generalize to other tasks. This is plausible, because for standard conflict tasks a generalization of conflict adaptation from one task to another (e.g., from a flanker to a Stroop task) does not always occur (see Braem et al. 2014, for a review). Further, one may conceive BCE trials with a free choice Task 1 as ones instantiating a different context than those with a forced choice Task 1. If this were true, a sequence with a prime trial that entailed a free choice Task 1 would mean a change of context to the test trial. Indeed, there is some evidence that sequential modulations (within dual-task settings) seem to depend on repetitions of task contexts (Fischer et al. 2010).

Conclusion

We investigated an alternative explanation to reduced S–R links for diminished BCEs in dual-task trials involving a free choice trial (Naefgen et al. 2017a). However, we observed no evidence supporting the idea that conflict adaptation induced by free choice tasks led to these smaller BCEs.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Appendix

This Appendix reports the analyses of Task 2 performance in Experiments 1 and 2 ("Experiment 1: Task 2 results" and "Experiment 2: Task 2 results" sections) and the full analyses of the 2 × 2 × 2 design employed in Experiment 1 ("Experiment 1, full design: Task 1 results" section for Task 1 performance and "Experiment 1, full design: Task 2 results" section for Task 2 performance).

Experiment 1: Task 2 results

Mean correct RT2s (2.61% excluded as outliers) are summarized in Table 4. Responses were faster in compatible trials than in incompatible trials, $t(35) = 6.05$, $p < .001$, showing an overall forward crosstalk effect (FCE). Contrast 1 was significant, $t(35) = 4.30$, $p < .001$, as was Contrast 2, $t(35) = 6.07$, $p < .001$. Contrast 1 interacted with compatibility, $t(35) = 11.61$, $p < .001$, and so did Contrast 2, $t(35) = 2.13$, $p = .040$. The latter indicates a reduced FCE following compatible free (vs. compatible forced) choice Task 1 trials.

Paired *t*-tests indicated significant FCEs for trials following compatible free choice prime trials, $t(35) = 7.14$, $p < .001$, $d = 1.68$, as well as compatible forced choice prime trials, $t(35) = 10.38$, $p < .001$, $d = 2.45$. Following incompatible forced choice prime trials, the FCE was reversed, $t(35) = -3.72$, $p = .001$, $d = -.88$.

Mean PE2s are summarized in Table 4. The compatibility in the test trial, $t(35) = 3.33$, $p = .002$, had a significant influence on PE2s. Furthermore, Contrast 1 was significant, $t(35) = 3.84$, $p < .001$, while Contrast 2 was not, $t(35) = 0.73$, $p = .469$. Contrast 1 interacted with compatibility, $t(35) = 6.30$, $p < .001$, while Contrast 2 did not $t(35) = 0.64$, $p = .523$. For the differences in PE2s between compatible and incompatible trials, paired *t*-tests indicated significant differences for trials following compatible free, $t(35) = 4.13$, $p < .001$, $d = 0.97$, and forced choice prime trials, $t(35) = 5.41$, $p < .001$, $d = 1.27$, as well as, in the other direction, those following incompatible forced choice prime trials, $t(35) = -3.35$, $p = .002$, $d = -0.79$.

Experiment 2: Task 2 results

Mean Task 2 RT2s (2.18% excluded as outliers) are summarized in Table 5. There was a significant FCE, $F(1,35) = 38.59$, $p < .001$, $\eta_p^2 = .97$, as well as a significant effect of the block type, $F(2,70) = 7.94$, $p = .001$, $\eta_p^2 = .18$, but no significant interaction, $F(2,70) = 0.46$, $p = .630$, $\eta_p^2 = .01$. Paired *t*-tests indicated significant FCEs for all block types, 25% free choices, $t(35) = 5.99$, $p < .001$, $d = 1.41$; 50% free choices, $t(35) = 5.34$, $p < .001$, $d = 1.26$; and 75% free choices, $t(35) = 4.20$, $p < .001$, $d = 0.99$.

Mean PE2s are summarized in Table 5. The compatibility in the test trial had a significant effect on PE2 s with fewer errors in compatible trials, $F(1,35) = 10.53$, $p = .003$, $\eta_p^2 = .23$. Neither the block type, $F(2,70) = .01$, $p = .985$, $\eta_p^2 < .01$, nor its interaction with compatibility, $F(2,70) = .10$, $p = .905$, $\eta_p^2 < .01$, was significant.

Experiment 1, full design: Task 1 results

This section describes RT1s (2.09% excluded as outliers) and PE1s of the full 2 × 2 × 2 (compatibility in the test trial × compatibility in the prime trial × task type in

Table 4 Mean correct response times (RT2) in milliseconds and percentages of errors (PE2) from Task 2 of Experiment 1 as a function of prime trial conflict type and R1–R2 compatibility

R1–R2 compatibility	Prime trial conflict type							
	Forced choice incompatible		Forced choice compatible		Free choice compatible		Free choice incompatible	
	RT2	PE2	RT2	PE2	RT2	PE2	RT2	PE2
Incompatible	919	2.4	1065	13.1	1124	11.7	1098	8.6
Compatible	994	8.4	864	3.6	967	3.8	1041	5.0
FCE	−75	−6.0	201	9.5	157	7.9	57	3.6

The FCE (forward crosstalk effect) row reports the difference between the mean of the compatible and incompatible trials

Table 5 Mean correct response times (RT2) in milliseconds and percent error (PE2) from Task 2 of Experiment 2 as a function of block type and R1–R2 compatibility

R1–R2 compatibility	Block type					
	25% free choices		50% free choices		75% free choices	
	RT2	PE2	RT2	PE2	RT2	PE2
Incompatible	1114	8.2	1163	8.6	1214	8.6
Compatible	1009	4.8	1072	4.7	1102	4.6
BCE	105	3.4	91	3.9	112	4.0

The FCE (forward crosstalk effect) row reports the difference between the mean of the compatible and incompatible trials

Table 6 Mean correct response times (RT1) in milliseconds and percentages of errors (PE1) from Task 1 of Experiment 1 as a function of prime trial R1–R2 compatibility, prime trial task type, and test trial R1–R2 compatibility

R1–R2 compatibility	Prime trial conflict type							
	Forced choice incompatible		Forced choice compatible		Free choice compatible		Free choice incompatible	
	RT1	PE1	RT1	PE1	RT1	PE1	RT1	PE1
Incompatible	563	3.7	676	11.3	744	15.2	704	7.3
Compatible	622	5.4	530	1.2	615	5.2	680	8.5
BCE	− 59	− 1.7	146	10.1	129	10.0	24	− 1.2

The BCE row reports the difference between the mean of the compatible and incompatible trials

the prime trial) design of Experiment 1. Only test trials were used in this analysis. Mean values are summarized in Table 6. There was a significant main effect of compatibility in the test trial, $F(1,35) = 31.77$, $p < .001$, $\eta_p^2 = .48$, and of task type in the prime trial, $F(1,35) = 65.61$, $p < .001$, $\eta_p^2 = .65$. There was no main effect of compatibility in the prime trial, $F(1,35) = 0.03$, $p = .874$, $\eta_p^2 < .01$. There were significant interactions between compatibility in the test and in the prime trial, $F(1,35) = 92.87$, $p < .001$, $\eta_p^2 = .73$, the compatibility in the test trial and the task type in the prime trial, $F(1,35) = 4.76$, $p = .036$, $\eta_p^2 = .12$, and between all three factors, $F(1,35) = 17.75$, $p < .001$, $\eta_p^2 = .34$. There was no significant interaction between task type and compatibility in the prime trial, $F(1,35) = 2.81$, $p = .103$, $\eta_p^2 = .07$.

For the PE1s, there were main effects for the compatibility in the test trial, $F(1,35) = 12.44$, $p = .001$, $\eta_p^2 = .26$, the compatibility in the prime trial, $F(1,35) = 5.01$, $p = .032$, $\eta_p^2 = .13$, as well as task type in the prime trial, $F(1,35) = 25.69$, $p < .001$, $\eta_p^2 = .42$. There was an interaction between compatibility of the test and the prime trial, $F(1,35) = 28.71$, $p < .001$, $\eta_p^2 = .45$. There was no interaction between the compatibility of the test trial and task type in the prime trial, $F(1,35) = 0.04$, $p = .852$, $\eta_p^2 < .01$, task type in the prime trial and compatibility in the prime trial, $F(1,35) = 0.48$, $p = .493$, $\eta_p^2 = .01$, nor between all three factors, $F(1,35) = 0.06$, $p = .815$, $\eta_p^2 < .01$.

Experiment 1, full design: Task 2 results

This section describes RT2s (2.45% excluded as outliers) and PEs of the full $2 \times 2 \times 2$ (compatibility in the test trial × compatibility in the prime trial × task type in the prime trial) design of Experiment 1. Only test trials were used in this analysis. Mean values are summarized in Table 4. There was a significant main effect of compatibility in the test trial, $F(1,35) = 32.48$, $p < .001$, $\eta_p^2 = .48$, and task type in the prime trial, $F(1,35) = 57.53$, $p < .001$, $\eta_p^2 = .62$. There was no main effect of compatibility in the prime trial, $F(1,35) = 0.91$, $p = .346$, $\eta_p^2 = .03$. There were significant interactions between compatibility in the test and the prime trial, $F(1,35) = 103.50$, $p < .001$, $\eta_p^2 = .75$, the compatibility in the test trial and task type in the prime trial, $F(1,35) = 5.97$, $p = .020$, $\eta_p^2 = .15$, and all three factors, $F(1,35) = 29.99$, $p < .001$, $\eta_p^2 = .46$. There was no significant interaction between compatibility and task type in the prime trial, $F(1,35) = 3.44$, $p = .072$, $\eta_p^2 = .09$.

For the PE2 s, there were main effects for the compatibility in the test trial, $F(1,35) = 12.33$, $p = .001$, $\eta_p^2 = .26$, and the compatibility in the prime trial, $F(1,35) = 10.28$, $p = .003$, $\eta_p^2 = .23$. There were significant interactions between compatibility in the test and in the prime trial, $F(1,35) = 33.38$, $p < .001$, $\eta_p^2 = .49$, the compatibility in the test trial and task type in the prime trial, $F(1,35) = 10.43$, $p = .003$, $\eta_p^2 = .23$, the compatibility and task type in the prime trial, $F(1,35) = 6.08$, $p = .019$, $\eta_p^2 = .15$, as well as all three factors, $F(1,35) = 11.45$, $p = .002$, $\eta_p^2 = .25$. There was no main effect for task type in the prime trial, $F(1,35) = 0.37$, $p = .548$, $\eta_p^2 = .01$.

References

Akçay Ç, Hazeltine E (2007) Conflict monitoring and feature overlap: two sources of sequential modulations. Psychon Bull Rev 14:742–748. https://doi.org/10.3758/BF03196831

Berlyne DE (1957) Conflict and choice time. Br J Psychol 48:106–118. https://doi.org/10.1111/j.2044-8295.1957.tb00606.x

Botvinick MM, Braver TS, Barch DM et al (2001) Conflict monitoring and cognitive control. Psychol Rev 108:624–652. https://doi.org/10.1037/0033-295X.108.3.624

Braem S, Abrahamse EL, Duthoo W, Notebaert W (2014) What determines the specificity of conflict adaptation? A review, critical analysis, and proposed synthesis. Front Psychol 5:1134. https://doi.org/10.3389/fpsyg.2014.01134

Bugg JM, Crump MJC (2012) In support of a distinction between voluntary and stimulus-driven control: a review of the literature on proportion congruent effects. Front Psychol 3:367. https://doi.org/10.3389/fpsyg.2012.00367

Crump MJC, Gong Z, Milliken B (2006) The context-specific proportion congruent Stroop effect: location as a contextual cue. Psychon Bull Rev 13:316–321. https://doi.org/10.3758/BF03193850

Dignath D, Janczyk M, Eder AB (2017) Phasic valence and arousal do not influence post-conflict adjustments in the Simon task. Acta Psychol 174:31–39. https://doi.org/10.1016/j.actpsy.2017.01.004

Ellenbogen R, Meiran N (2008) Working memory involvement in dual-task performance: evidence from the backward compatibility effect. Mem Cognit 36:968–978. https://doi.org/10.3758/MC.36.5.968

Ellenbogen R, Meiran N (2011) Objects and events as determinants of parallel processing in dual tasks: evidence from the backward compatibility effect. J Exp Psychol Hum Percept Perform 37:152–167. https://doi.org/10.1037/a0019958

Eriksen BA, Eriksen CW (1974) Effects of noise letters upon the identification of a target letter in a nonsearch task. Percept Psychophys 16:143–149. https://doi.org/10.3758/BF03203267

Fischer R, Dreisbach G (2015) Predicting high levels of multitasking reduces between-tasks interactions. J Exp Psychol Hum Percept Perform 41:1482–1487. https://doi.org/10.1037/xhp0000157

Fischer R, Plessow F, Kunde W, Kiesel A (2010) Trial-to-trial modulations of the Simon effect in conditions of attentional limitations: evidence from dual tasks. J Exp Psychol Hum Percept Perform 36:1576–1594. https://doi.org/10.1037/a0019326

Fischer R, Gottschalk C, Dreisbach G (2014) Context-sensitive adjustment of cognitive control in dual-task performance. J Exp Psychol Learn Mem Cognit 40:399–416. https://doi.org/10.1037/a0034310

Frith CD, Friston K, Liddle PF, Frackowiak RS (1991) Willed action and the prefrontal cortex in man: a study with PET. Proc Biol Sci 244:241–246. https://doi.org/10.1098/rspb.1991.0077

Giammarco M, Thomson SJ, Watter S (2016) Dual-task backward compatibility effects are episodically mediated. Atten Percept Psychophys 78:520–541. https://doi.org/10.3758/s13414-015-0998-y

Gollwitzer PM (1999) Implementation intentions: strong effects of simple plans. Am Psychol 54:493–503. https://doi.org/10.1037/0003-066X.54.7.493

Goschke T, Dreisbach G (2008) Conflict-triggered goal shielding: response conflicts attenuate background monitoring for prospective memory cues. Psychol Sci 19:25–32. https://doi.org/10.1111/j.1467-9280.2008.02042.x

Gratton G, Coles MGH, Donchin E (1992) Optimizing the use of information: strategic control of activation of responses. J Exp Psychol Gen 121:480–506. https://doi.org/10.1037/0096-3445.121.4.480

Herwig A, Prinz W, Waszak F (2007) Two modes of sensorimotor integration in intention-based and stimulus-based actions. Q J Exp Psychol 60:1540–1554. https://doi.org/10.1080/17470210601119134

Hommel B (1998) Automatic stimulus–response translation in dual-task performance. J Exp Psychol Hum Percept Perform 24:1368–1384. https://doi.org/10.1037/0096-1523.24.5.1368

Hommel B, Eglau B (2002) Control of stimulus-response translation in dual-task performance. Psychol Res 66:260–273. https://doi.org/10.1007/s00426-002-0100-y

Janczyk M (2016) Sequential modulation of backward crosstalk and task-shielding in dual-tasking. J Exp Psychol Hum Percept Perform 42:631–647. https://doi.org/10.1037/xhp0000170

Janczyk M, Leuthold H (2018) Effector system-specific sequential modulations of congruency effects. Psychon Bull Rev 25:1066–1072. https://doi.org/10.3758/s13423-017-1311-y

Janczyk M, Pfister R, Hommel B, Kunde W (2014) Who is talking in backward crosstalk? Disentangling response- from goal-conflict in dual-task performance. Cognition 132:30–43. https://doi.org/10.1016/j.cognition.2014.03.001

Janczyk M, Dambacher M, Bieleke M, Gollwitzer PM (2015a) The benefit of no choice: goal-directed plans enhance perceptual processing. Psychol Res 79:206–220. https://doi.org/10.1007/s00426-014-0549-5

Janczyk M, Nolden S, Jolicoeur P (2015b) No differences in dual-task costs between forced- and free-choice tasks. Psychol Res 79:463–477. https://doi.org/10.1007/s00426-014-0580-6

Janczyk M, Renas S, Durst M (2018) Identifying the locus of compatibility-based backward crosstalk: evidence from an extended PRP paradigm. J Exp Psychol Hum Percept Perform 44:261–276. https://doi.org/10.1037/xhp0000445

Kiesel A, Wagener A, Kunde W et al (2006) Unconscious manipulation of free choice in humans. Conscious Cognit 15:397–408. https://doi.org/10.1016/j.concog.2005.10.002

Lien M-C, Proctor RW (2000) Multiple spatial correspondence effects on dual-task performance. J Exp Psychol Hum Percept Perform 26(4):1260–1280. https://doi.org/10.1037/0096-1523.26.4.1260

Lien M-C, Proctor RW (2002) Stimulus-response compatibility and psychological refractory period effects: implications for response selection. Psychon Bull Rev 9:212–238. https://doi.org/10.3758/BF03196277

Mattler U, Palmer S (2012) Time course of free-choice priming effects explained by a simple accumulator model. Cognition 123:347–360. https://doi.org/10.1016/j.cognition.2012.03.002

Mayr U, Awh E (2009) The elusive link between conflict and conflict adaptation. Psychol Res 73:794–802. https://doi.org/10.1007/s00426-008-0191-1

Miller J, Ulrich R (2008) Bimanual response grouping in dual-task paradigms. Q J Exp Psychol 61:999–1019. https://doi.org/10.1080/17470210701434540

Naefgen C, Janczyk M (2018) Free choice tasks as random generation tasks: an investigation through working memory manipulations. Exp Brain Res. https://doi.org/10.1007/s00221-018-5295-2

Naefgen C, Caissie AF, Janczyk M (2017a) Stimulus-response links and the backward crosstalk effect—a comparison of forced- and free-choice tasks. Acta Psychol 177:23–29. https://doi.org/10.1016/j.actpsy.2017.03.010

Naefgen C, Dambacher M, Janczyk M (2017b) Why free choices take longer than forced choices: evidence from response threshold manipulations. Psychol Res. https://doi.org/10.1007/s00426-017-0887-1

Notebaert W, Gevers W, Verbruggen F, Liefooghe B (2006) Top-down and bottom-up sequential modulations of congruency effects. Psychon Bull Rev 13:112–117. https://doi.org/10.3758/BF03193821

Pashler H (1984) Processing stages in overlapping tasks: evidence for a central bottleneck. J Exp Psychol Hum Percept Perform 10:358–377. https://doi.org/10.1037/0096-1523.10.3.358

Pashler H (1994) Dual-task interference in simple tasks: data and theory. Psychol Bull 116:220–244. https://doi.org/10.1037/0033-2909.116.2.220

Pfister R, Janczyk M (2013) Confidence intervals for two sample means: calculation, interpretation, and a few simple rules. Adv Cogn Psychol 9:74–80. https://doi.org/10.2478/v10053-008-0133-x

Renas S, Durst M, Janczyk M (2017) Action effect features, but not anatomical features, determine the backward crosstalk effect: evidence from crossed-hands experiments. Psychol Res. https://doi.org/10.1007/s00426-017-0873-7

Scherbaum S, Fischer R, Dshemuchadse M, Goschke T (2011) The dynamics of cognitive control: evidence for within-trial conflict adaptation from frequency-tagged EEG. Psychophysiology 48:591–600. https://doi.org/10.1111/j.1469-8986.2010.01137.x

Scherbaum S, Gottschalk C, Dshemuchadse M, Fischer R (2015) Action dynamics in multitasking: the impact of additional task factors on the execution of the prioritized motor movement. Front Psychol 6:934. https://doi.org/10.3389/fpsyg.2015.00934

Schmidt JR (2013) Temporal learning and list-level proportion congruency: conflict adaptation or learning when to respond? PLoS ONE 8:e82320. https://doi.org/10.1371/journal.pone.0082320

Schuch S, Dignath D, Steinhauser M, Janczyk M (2018) Monitoring and control in multitasking. Psychon Bull Rev. https://doi.org/10.3758/s13423-018-1512-z

Stürmer B, Leuthold H (2003) Control over response priming in visuomotor processing: a lateralized event-related potential study. Exp Brain Res 153:35–44. https://doi.org/10.1007/s00221-003-1579-1

Stürmer B, Leuthold H, Soetens E et al (2002) Control over location-based response activation in the Simon task: behavioral and electrophysiological evidence. J Exp Psychol Hum Percept Perform 28:1345–1363. https://doi.org/10.1037/0096-1523.28.6.1345

Thomson SJ, Danis LK, Watter S (2015) PRP training shows Task1 response selection is the locus of the backward response compatibility effect. Psychon Bull Rev 22:212–218. https://doi.org/10.3758/s13423-014-0660-z

Ulrich R, Miller J (2008) Response grouping in the psychological refractory period (PRP) paradigm: models and contamination effects. Cogn Psychol 57:75–121. https://doi.org/10.1016/j.cogpsych.2007.06.004

Watter S, Logan GD (2006) Parallel response selection in dual-task situations. Percept Psychophys 68:254–277. https://doi.org/10.3758/BF03193674

Wirth R, Janczyk M, Kunde W (2018) Effect monitoring in dual-task performance. J Exp Psychol Learn Mem Cognit 44:553–571. https://doi.org/10.1037/xlm0000474