Cognitive control is task specific: Further evidence against the idea of domain-general conflict adaptation

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Abstract

Adaptive control refers to flexible adjustments in control settings in response to conflicting situations. There has been a long-standing debate as to whether this adaptation relies on a domain-general or domain-specific process. Recent models predict a U-shaped relation where only highly similar or highly dissimilar tasks show adaptation across tasks, because only those tasks can be represented or activated in parallel. While there has been an abundance of evidence for adaptation within and across highly similar tasks, only some recent studies have reported adaptation across highly dissimilar tasks, with some failures to replicate. In order to further investigate this, we interleaved two very different conflict tasks, a manual multi-source interference task and a vocal picture-word interference task. We ran this experiment in Dutch (Experiment 1) and Mandarin (Experiment 2). Across the two experiments, results show no cross-task conflict adaptation. These results do not fit with the suggestion of domain-general adaptive processes nor with the hypothesis of a U-shaped model. Instead, our results are most compatible with a task-specific view on the mechanisms behind adaptive control.

Keywords: cognitive control, conflict adaptation, congruency sequence effect, domain generality

Introduction

In daily life, we often need to suppress sudden urges and select more appropriate actions to achieve our goals. For example, when driving on a busy road, taxi drivers need to focus their attention on the traffic, instead of being distracted by interesting conversations of their passengers. Goal-directed behavior like this relies on the ability to focus on target-relevant information and ignore irrelevant distracters – a function often referred to as cognitive control.

In the laboratory, cognitive control is often studied using congruency tasks in which participants need to ignore task-irrelevant information and their associated responses (Bush et al., 2003; Eriksen & Eriksen, 1974; Simon & Berbaum, 1990; Stroop, 1935). For example, in a flanker task, participants need to respond to a central target while ignoring irrelevant flankers (Eriksen & Eriksen, 1974). The *congruency effect* here (i.e., flanker effect) is the observation that response times are shorter when the target is flanked by congruent flankers (e.g., <<<<<), compared to incongruent flankers (e.g., >><>>). Interestingly, the congruency effect is also modulated by the congruency of previous trials. This is referred to as *congruency sequence effect (CSE)*, which is the observation that the congruency effect in conflict tasks tends to decrease following incongruent compare to congruent trials, also known as conflict adaptation or the Gratton effect (Braem et al., 2014; Braem et al., 2019; Duthoo et al., 2014; Egner et al., 2007; Gratton et al., 1992). While mostly studied in the context of a single task, an important question has been whether the CSE can also be observed across tasks (Becker et al., 2024; Braem et al., 2014). That is, when experiencing a conflict in one task, will this also change attentional settings on a subsequent different task. If so, the latter could suggest that we rely on domain-general processes for these transient adaptations in cognitive control.

One of the most prominent theories developed for explaining the CSE is the conflict monitoring theory (Botvinick et al., 2001). Conflict monitoring theory holds that this effect is due to a continuous monitoring for cognitive conflict by the anterior cingulate cortex, which in turn sends a signal to the dorso-lateral and ventro-lateral prefrontal cortex to make adaptive changes in attentional control settings (Botvinick et al., 2004; van Veen & Carter, 2002). These adaptive changes improve cognitive control and facilitate dealing with task-irrelevant information on the next trial. Specifically, when the previous trial was a congruent trial, the level of cognitive control will be relatively low. On the contrary, when the previous trial was an incongruent trial, control will be upregulated, resulting in a smaller congruency effect on the next trial. The original model describes adaptation by means of task-specific adjustments of control settings for task relevant and task irrelevant information. Therefore, when the two tasks do not share any of the task-relevant or task-irrelevant representations, this model predicts no cross-task adaptation.

However, other adaptation mechanisms have been described that assume a more domain-general mechanism. Thompson-Schill and colleagues (1997; Nozari & Thompson-Schill, 2016) assume that control is mediated by transient activation in the prefrontal cortex. When an incongruent trial is encountered in a given task, prefrontal cortex is activated and implements control. This activation is then hypothesized to improve performance on the next incongruent trial, no matter which task it appears in (see also, Ness et al., 2023). One problem with this domain-general account is that it remains unclear how the prefrontal cortex knows which task representation is currently relevant. In response to this problem, Verguts and Notebaert (2008, 2009) described conflict adaptation in terms of a conflict-based learning model. Upon conflict detection, a Hebbian learning signal is sent throughout the brain that will affect all currently active associations. Because task-relevant and task-specific associations are usually the most active when just having performed an incongruent trial, the adaptation-by-binding account tends to strengthen those and predict task-specific control.

Importantly, as noted by Braem and colleagues (2014), this model can also predict CSE across tasks. Specifically, starting from the assumption that tasks relying on non-overlapping representations can be actively and simultaneously maintained in working memory without much interference, one should be able to observe a congruency sequence effect across tasks. This also fits with theories on cognitive control that have come to (re)emphasize that the limited capacity for task control is mostly determined by the reliance of tasks on shared resources (Musslick & Cohen, 2021). Namely, when task features partially overlap or belong to similar categories (as opposed to no overlap or complete overlap), there is more likely to be interference preventing the simultaneous maintenance of both tasks or contexts in working memory (Oberauer et al., 2012). Accordingly, Braem and colleagues (2014) proposed a U-shaped function between task (dis)similarity and cross-task congruency sequence effects. For example, when two tasks use the same stimulus set and relevant dimension, and non-interfering response sets, both tasks can co-exist in working memory (and presumably be conceived as one task), and a cross-task congruency sequence effect can be observed (Akçay & Hazeltine, 2008). Second, when only parts of two tasks overlap, but not others, the two tasks will interfere, only allowing for one task to be active at any given time, thereby preventing the adaptation processes to allow for a CSE across tasks (Cracco et al., 2022; Dignath et al., 2019; Notebaert & Verguts, 2008). Finally, when two contexts or tasks are completely different and non-overlapping, it is theoretically possible that they can be activated in parallel without much interference (e.g., Musslick & Cohen, 2021), and cross-task congruency sequence effects can be observed (Kan et al., 2013; Kleiman et al., 2014).

Indeed, there are studies showing cross-task congruency sequence effects between two considerably distinct tasks. For example, Kan et al. (2013) observed a cross-task congruency sequence effects between a sentence comprehension task and a Stroop task (Experiment 1) and between a Necker cube task and Stroop task (Experiment 2). Participants either needed to read a potentially ambiguous sentence, or passively watch perceptual ambiguous Necker cubes. In both experiments, the authors showed reduced Stroop congruency effects following ambiguous stimuli in the other task. Some later studies also showed cross-task congruency sequence effects in similar paradigms. For example, similar observations where made when using a Stroop task and sentence comprehension task using eye-tracking (Hsu & Novick, 2016), a flanker task or perceptual conflict task and sentence comprehension task using eye-tracking (Hsu et al., 2021), or a Stroop task and sentence comprehension task using EEG (Ovans et al., 2022).

However, there has also been considerable evidence against these cross-task congruency sequence effects (see Braem et al., 2014, for a review). For example, Aczel et al. (2021) tried to replicate Kan et al. (2013), by similarly interleaving a sentence comprehension task and a Stroop task, but the cross-task congruency sequence effect was only observed in the error rate data, not reaction time. In a second experiment, they tried to replicate this effect between the perceptual and verbal domain, but no cross-task congruency sequence effect was observed. Similarly, Dudschig (2022) failed to replicate Kan et al. (2013) across two experiments, and even documented a reversed congruency sequence effect in one of the two studies. In a similar vein, Freund and Nozari (2018) found no cross-task CSE between a prime-probe task or sentence reading task and a picture-word interference task, despite finding within-task CSE for trials that were farther apart in time and separated by intervening trials from the other task. Together, those studies seem to suggest that there is mixed evidence at best, for the idea that adaptive control can be observed across two tasks, when both tasks are distinctively different.

In order to better define task dissimilarity, we defined task dissimilarity along nine dimensions (Zhu et al., 2024): 1) stimulus domain, 2) stimulus type, 3) stimulus identity, 4) response mode, 5) response identity, 6) conflict type, 7) relevant dimension, and 8) irrelevant dimension, 9) sensory modality (for more detailed definitions, see Supplementary Table 4). After extensively searching the literature, we identified two studies that investigated the CSE in reaction times or accuracy, where the two tasks differed on eight of those dimensions (Freund & Nozari, 2018; Wirth et al., 2023), and another five studies on seven dimensions (Aczel et al., 2021; Cracco et al., 2022; Dudschig, 2022; Kan et al., 2013; Simi et al., 2023). For example, in the study by Kan et al. (2013), the response modality was the same (i.e., participants used hand keypresses for both the Stroop and sentence tasks) and they used the same sensory modality for the two different tasks (both visual; see also, Freund & Nozari, 2018).

In the present study, we interleaved a Multi-Source Interference Task with a Picture-Word Interference task, to assess the potential for congruency sequence effects across distinct tasks, as a new test of the U-shaped prediction by Braem and colleagues

(2014). We chose these two tasks because they are dissimilar on most of the above-mentioned dimensions, and, most importantly, employed different response modality (manual vs. vocal), compared to Kan et al. (2013). More specifically, they came from different task domains (cognitive vs. linguistic), employed different stimulus types and identity (numbers vs. pictures and words), different responses modes and identity (manual vs. vocal), different conflict types (flanker and Simon vs. Stroop-like), different task-relevant dimensions (unique number vs. picture) and different task-irrelevant dimensions (flanker and position vs. word meaning). As such, we assumed task representations with such high dissimilarity can be activated simultaneously in working memory without much interference, and, therefore, a cross-task CSE could be observed when strengthening all active task representations after conflict (e.g., Braem et al., 2014; Verguts & Notebaert, 2008). Moreover, the multi-source interference task addresses a concern about the level of conflict. It has been proposed that conflict can be at the stimulus or the response level (e.g., Frühholz et al., 2011). Therefore, the absence of cross-task CSEs in previous studies may be attributed to the two tasks tapping into conflict at different levels of information processing. The MSI task allows us to separately manipulate conflict at the stimulus level, response level, and both levels. Consequently, this task can also be used to examine alternative explanations that may depend on the level of conflict. In addition, the samples from our two experiments come from different cultures, which helped to better verify the generality of the results.

Two earlier pilot studies seemed to show first evidence for a cross-task CSE. However, these pilot studies used a suboptimal trial randomization resulting in the exact same trial sequence for all participants. Therefore, it is possible that this particular item order included more easy items on congruency sequences where performance benefits are expected, inadvertently causing the pattern of a congruency sequence effect. Motivated by these first findings, the present study employed an improved design with optimal randomization.

Methods

Participants

We aimed to include 50 participants for each experiment to achieve more statistical power (Brysbaert, 2019), necessary to detect an assumed small to medium sample size of .4 with a statistical power of 80%. Seventy-six students from Ghent University participated in Experiment 1 for credit. All were native Dutch speakers and right-handed. Fifteen participants were excluded because of equipment problems (a malfunctioning of the microphone), five participants because of poor performance in the multi-source interference task (made more errors than 2 standard deviations by mean), and seven participants were excluded because of high noise in the vocal recordings during the picture-word interference task. Fifty students from Jiangsu Normal University participated in Experiment 2 for 30 Chinese yuan (about 4 euro, we only recruited 50 participants for financial reasons). All were native Chinese speakers and right-handed. Ten participants were excluded because of equipment problems, and one participant was excluded because of using the wrong response rules in the multi-source interference task. All of the remaining 49 participants (40 females; age range 18-22years; mean age, 18.8 years) in Experiment 1, and 39 participants (33 females; age range 19-27 years; mean age, 23.1 years) in Experiment 2, reported normal or corrected-to-normal vision and no history of neurological disorders.

This study falls under the General Ethical Protocol of Ethical Committee Psychology and Educational Sciences, Ghent University (Experiment 1) and Ethical Committee of School of Linguistic Sciences and Arts, Jiangsu Normal University (Experiment 2).

Task and Design

We interleaved a multi-source interference task with a picture-word interference task. In the picture-word interference task, participants saw a picture with a word printed in the center. The word was either the picture's name or a semantic competitor of the picture's name. Participants were required to name the picture out loud and ignore the word. Each picture-word interference trial was preceded by a multi-source interference trial, in which three numbers were displayed, one of them was always different from the others, and participants were asked to respond to the unique number by pressing a button (see Figure 1).

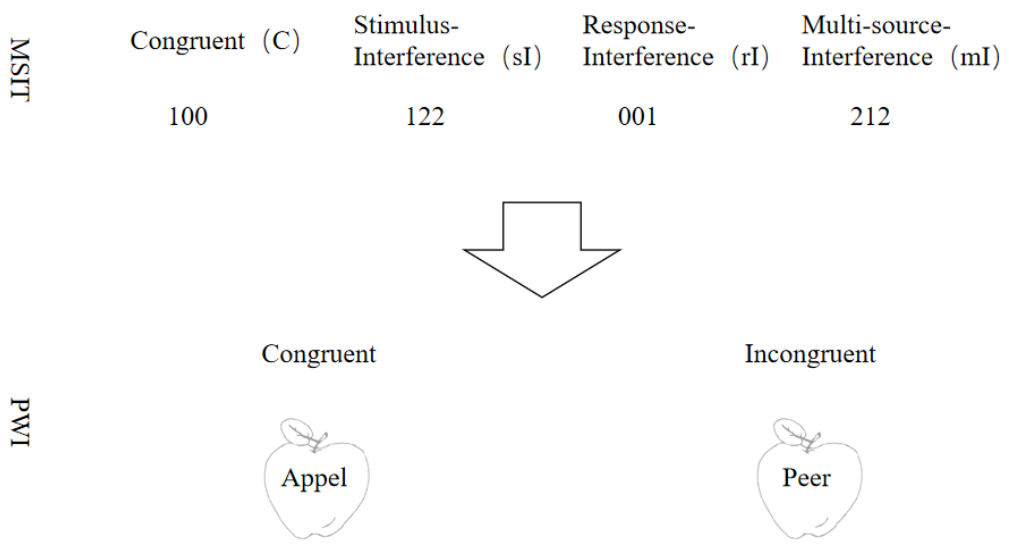

Figure 1. General experimental design. A multi-source interference task stimulus always followed by a picture-word interference task stimulus. In Experiment 1, Dutch words were used, while in Experiment 2, Chinese words were used (not shown in this figure). We created 8 types of pairings: 4 multi-source interference conditions* 2 picture-word interference conditions.

Multi-source interference task. The multi-source interference task was modeled after Bush and Shin (2006) and Bush et al. (2003). Participants were given a keyboard and instructed to use their index finger for the number 1 button, middle finger for number 2, and ring finger for number 3 to respond to visual stimuli 1, 2 and 3, correspondingly. The numbers 0, 1, 2, 3 were used to create sets of three-digits numbers as stimuli, in which two numbers were always the same (distractors) and the remaining unique number was the target (e.g., in 100, “1” is the target number and the other two numbers are the distractors). In congruent trials, the spatial position of the responding finger matched with that of the target number; and distractors only included the number 0, which did not match any response buttons (e.g., for the stimulus “020”, the target number 2 in the middle required a response with the subjects’ middle finger). In response interference trials, the spatial position of the responding finger mismatched with that of the target number (e.g., for the stimulus “200”, the target number 2 on the left had to be responded to with the middle finger). In stimulus interference trials, the spatial position of the responding finger matched with that of the target number, but distractors included numbers 1, 2, or 3, all of which matched a possible response key (e.g., for the stimulus “133”, numbers 3 were distractors for the target number 1). In multi-source interference trials, the spatial position of the responding finger mismatched with that of the target number *and* distractors included numbers 1, 2, or 3 (e.g., for the stimulus “233”, the target number 2 on the left required a response with the middle finger and number 3 was a distractor for the target number 2). There were 288 trials in total, with 144 trials for each of the congruent and incongruent conditions. The incongruent condition contained 48 trials of each of the response-, stimulus- and multi-source sub-conditions.

Picture-word interference task. Picture-word interference task was modeled after Meyer and Schriefers (1991). Participants saw pictures with words printed in the center and were asked to name the picture as quickly and accurately as possible and ignore the word. In the congruent condition, the word was the picture’s name (e.g., word “Apple” printed on the picture apple). In the incongruent condition, the word was a semantic competitor (e.g., the word “Peer”, pear in Dutch, printed on the picture apple). Seventy-two line drawings were selected from a normed database (Severens et al., 2005). For Exp 1 (Dutch), 72 words were selected as distractors. The lexical frequency and length of Dutch words were indexed by SUBTLEX-NL database (Brysbaert et al., 2018; Keuleers et al., 2010), then tested by paired t-test, results showed no difference between target and distractor (frequency: t_{71}=0.676, p= .501; length: t_{71}=0.942, p= .349). See Table S1 for more information. For Exp 2 (Mandarin), to increase the congruency effect, 144 (two per target picture) were selected as distractors to weaken the association between the target picture and specific distractor. For example, the target picture apple was once paired with the distractor word “梨子 (pear)” and once with “桃子 (peach)”. These were balanced across the different incongruent PWI trials, but not across the different congruency sequences. This means 50% incongruent PWI trials were randomly assigned with one distractor word, and other 50% with the other. For the same purpose, the transparency of the background pictures was set to 55% but not word prints. The Chinese picture and word stimuli were selected using an independent rating study on 35 participants who did not participate in either experiment. Participants were presented with a set of 132 picture and words, and rated each picture for familiarity. They also rated how similar each word was in meaning to each picture. Pictures with highest familiarity scores and distractor words with highest semantic similarity to target pictures were chosen for the main experiment. Also, the Mandarin pictures and associated target words were all disyllabic (two Chinese characters) and picked based on their high picture to word naming agreement. In order to create a larger congruency effect, words always appeared 100 ms earlier than pictures, and a blank screen of 50 ms was set between words and pictures (Smith & Magee, 1980) in both experiments. We also fully randomized the assignment of items to conditions to ensure that any potential effects of semantic interference will not affect the CSE. As such, even if cumulative semantic interference or facilitation (e.g., Oppenheim & Nozari, 2024) is at work, it will be across different conditions across different participants, eliminating the possibility of systematically contaminating the CSEs of interest.

Interleaved multi-source-to-picture-word interference sequences. For each trial, we combined a multi-source stimulus and picture-word stimulus as a pair, and balanced the proportion of congruent and incongruent trials in each task. To test the cross-task CSE, we created eight pairings of interest by factorially combining the four congruency types of the multi-source interference task (congruent, response incongruent, stimulus incongruent, multi-source incongruent) followed by the two possible congruency types of the picture-word interference task (congruent, incongruent). All eight types of congruency sequences were balanced within a block. We did not balance congruency sequences across pairs within tasks. Our picture and word selection, together with the experiment code, can be found online: [OSF| Cognitive control is task specific: Further evidence against the idea of domain-general conflict adaptation].

Material and Procedure

The experiment was run in PsychoPy3 software (Peirce et al., 2019). Stimuli were displayed at the center of the screen in white background. Stimuli were displayed at the center of the screen against a white background. For the MSIT task, the numbers were presented in Sim Hei font in black ink. The stimuli were converted to images with a size of 115 × 65 pixels. For the PWI task, all target pictures were standardized to 250 × 250 pixels, with the interfering words in Times New Rome font, size 8, centered in the images. The monitor is approximately 35 cm in front of the participants. Vocal responses for the picture-word interference task were registered using an Audio-Technica microphone, recorded digitally, and transcribed offline for the identification of errors. Response times for the picture-word interference task were computed in MATLAB (R2019a, The MathWorks, Inc.), by a speech processing toolbox SAP-VOICEBOX (Brookes, 1997, 2009). A random subset of calculated reaction time data was manually double checked by the experimenter to ensure the decoding accuracy. Response times for the multi-source interference task were registered using the keyboard.

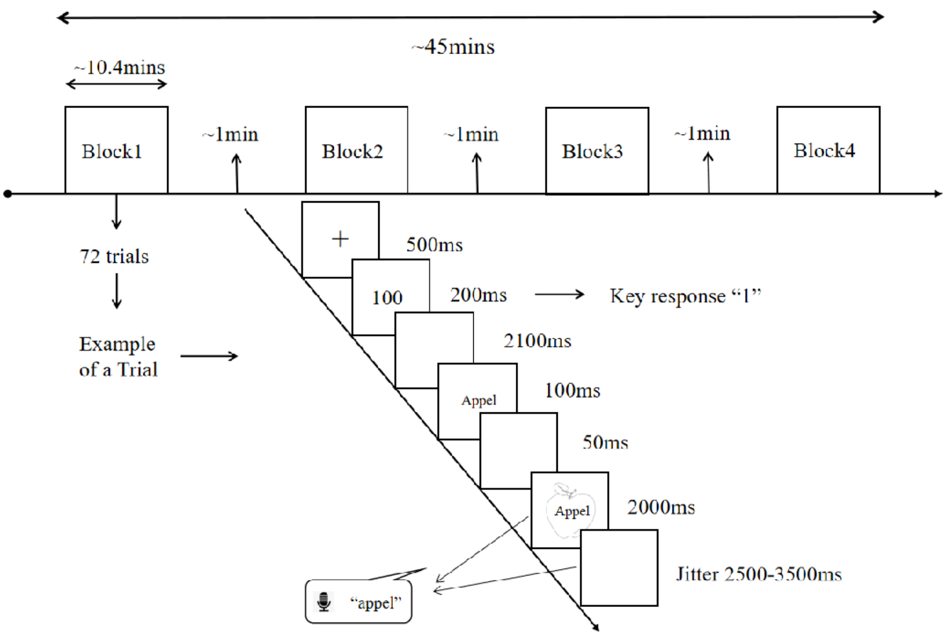

Figure 2. General procedure.

A trial is described in Figure 2. It started with a fixation "+" for 500 ms, followed by the multi-source stimulus for 200 ms and a fixed 2100 ms blank screen. Subjects could respond from the onset of the stimulus till the end of the blank screen. After the blank was the picture-word stimulus, which began with the presentation of the word for 100 ms, followed by a blank screen during 50 ms. The picture stimulus appeared immediately after, together with the word again, and stayed on screen for 2000 ms, after which the screen remained blank for a random period between 2500 to 3500 ms (mean of 3000 ms). Participants could name the picture from the stimulus onset till the end of the blank screen.

In the present study, we presented four blocks, each block including 72 pairings (each pairing appears in the same frequency). Each picture appeared once in each block. Before the experiment, participants performed ten trials of practice to familiarize themselves with the experimental process. A new trial list was randomly generated for each participant.

Analysis

The data were analyzed using JASP (Version 0.17.3; JASP Team, 2023) and R software (Version 4.0.2; R Development Core Team, 2014). For both tasks, we collected response time and error rate data. Trials with RTs with more than 3 standard deviations longer than the grand average RTs per condition and subject were excluded from analysis (Experiment 1: 1.5%, Experiment 2: 1.29%). Vocal responses under 400ms were rejected as noise (Experiment 1: 3.32%, Experiment 2: 2.73%). A one-way repeated measures ANOVA was used to test the effect of the multi-source interference task. After excluding trials following error trials, mean response times from all correct responses and mean error rates on the picture-word interference task were entered into a 4×2 repeated-measures ANOVA with factors "previous congruency" and "current congruency".

Results

Experiment 1 (Dutch)

Error rates

Multi-source interference task.

The error rates on the multi-source interference task showed a significant main effect of congruency type, $F(3, 192) = 13.915$, $p < .001$, $\eta_p^2 = 0.179$. The sample effect tests showed that the mean error rates were lower in congruent trials compared to multi-source incongruent trials, $t_{48} = -6.218$, $p < .001$, $MD = 13.2$ %, and response incongruent trials: $t_{48} = -3.009$, $p = .016$, $MD = 6.4$ %, but not in stimulus incongruent trials, $t_{48} = -1.645$, $p = .356$, $MD = 3.5$ %, indicating an interference effect in multi-source and response interference trials. Also, the multi-source interference trials showed the greatest interference effect comparted to the others (to response incongruent: $t_{48} = 3.209$, $p = .008$, $MD = 6.8$ %; stimulus incongruent: $t_{48} = 4.573$, $p < .001$, $MD = 9.7$ %). There was no significant difference between stimulus and response interference trials, $t_{48} = 1.364$, $p = .524$, $MD = 2.9$ %.

Picture-word interference task. The mean error rate in Experiment 1 was 4.4 %. The main effect of current congruency was also significant in the picture-word interference task, $F(1, 48) = 42.180$, $p < .001$, $\eta_p^2 = 0.468$, indicating that mean error rate was higher on incongruent trials than congruent trials. The main effect of previous congruency was not significant, $F(3, 144) = 0.247$, $p = .864$, $\eta_p^2 = 0.005$, nor was the interaction between previous and current congruency, $F(3, 144) = 0.664$, $p = .576$, $\eta_p^2 = 0.014$.

Furthermore, three separate repeated measure 2 × 2 ANOVAs showed that there was no significant interaction when previous congruency only included congruent and multi-source interference trials, $F(1, 48) = 0.472$, $p = .495$, $\eta_p^2 = 0.010$, congruent and response incongruent trials, $F(1, 48) = 2.216$, $p = .143$, $\eta_p^2 = 0.044$, or congruent and stimulus incongruent trials, $F(1, 48) = 1.449$, $p = .235$, $\eta_p^2 = 0.029$, indicating there was no cross-task congruency sequence effect across the two tasks.

Reaction times

Multi-source interference task.

The response times on the multi-source interference task showed a significant main effect of congruency type, $F(3, 192) = 76.040$, $p < .001$, $\eta_p^2 = 0.55$ (see Figure 3, left panel). The sample effect tests showed that the mean RT was faster in congruent trials compared to incongruent trials (multi-source: $t_{48} = -14.860$, $p < .001$, $MD = 339$ ms; response incongruent: $t_{48} = -5.297$, $p < .001$, $MD = 121$ ms; stimulus incongruent: $t_{48} = -7.623$, $p < .001$, $MD = 174$ ms), indicating an interference effect in multi-source, stimulus and response interference trials. Also, the multi-source interference trials showed the greatest interference effect comparted to the others (to response incongruent: $t_{48} = 9.563$, $p < .001$, $MD = 218$ ms; stimulus incongruent: $t_{48} = 7.238$, $p < .001$, $MD = 162$ ms). There was no significant difference between stimulus and response interference trials, $t_{49} = -2.326$, $p = .096$, $MD = 53$ ms.

Picture-word interference task.

The main effect of current congruency was also significant in the picture-word interference task, $F(1, 48) = 207.757$, $p < .001$, $\eta_p^2 = 0.812$, because the mean RT was slower in incongruent trials compare to congruent trials. The main effect of previous congruency was not significant, $F(3, 144) = 1.061$, $p = .368$, $\eta_p^2 = 0.022$, nor was the interaction between previous and current congruency, $F(3, 144) = 0.928$, $p = .429$, $\eta_p^2 = 0.019$. See Table 1 and 2 for more details.

Table 1. Mean reaction time (RT, in ms) in PWI task as function of MSIT task in Experiment 1 and 2.

	Experiment 1		**Experiment 2**	
MSIT	Congruent	Incongruent	Congruent	Incongruent
C	938 (129)	1107 (142)	987 (138)	1134 (128)
rI	941 (133)	1131 (164)	952 (139)	1137 (151)
sI	943 (146)	1121 (165)	982 (141)	1149 (143)
mI	950 (145)	1115 (158)	966 (135)	1144 (146)

Note. Standard deviations are given in parentheses.

Table 2. Mean percentage of error rates (ER) in PWI task as function of MSIT task in Experiment 1 and 2.

	Experiment 1		**Experiment 2**	
MSIT	Congruent	Incongruent	Congruent	Incongruent
C	2.1 (4.0)	6.5 (6.2)	0.1 (0.7)	1.1 (3.8)
rI	1.7 (4.3)	7.5 (7.8)	0.0 (0.0)	0.4 (1.7)
sI	2.0 (4.4)	7.3 (7.9)	0.5 (2.2)	1.2 (4.5)
mI	2.2 (5.9)	7.2 (8.5)	0.4 (1.7)	1.2 (4.8)

Note. Standard deviations are given in parentheses.

Furthermore, three separate repeated measure 2 × 2 ANOVAs showed that there was no significant interaction when previous congruency only included congruent and multi-source interference trials, $F(1, 48) = 0.119$, $p = .732$, $\eta_p^2 = 0.002$, congruent and response incongruent trials, $F(1, 48) = 1.807$, $p = .185$, $\eta_p^2 = 0.036$, or congruent and stimulus incongruent trials, $F(1, 48) = 0.287$, $p = .595$, $\eta_p^2 = 0.006$, indicating there was no cross-task congruency sequence effect across the two tasks, as shown in Figure 4, right panel.

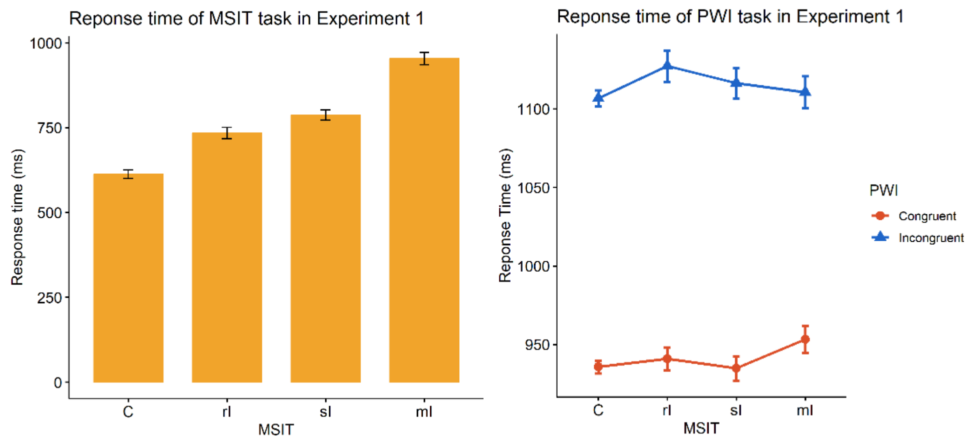

Figure 3. Mean response time as a function of multi-source interference task (C: congruent, sI: Stimulus Interference, rI: Response Interference, mI: Multi-source Interference) and picture-word interference task in Experiment 1. The error bars indicate standard error of the mean for each condition.

Experiment 2 (Mandarin)

Error rates

Multi-source interference task. The error rates on the multi-source interference task showed a significant main effect of congruency type, $F(3, 152) = 20.426$, $p < .001$, $\eta_p^2 = 0.287$. The sample effect tests showed that the mean error rates were lower on congruent trials compared to multi-source incongruent trials, $t_{38} = -7.132$, $p < .001$, *MD* = 5 %, and response incongruent trials: $t_{38} = -3.096$, $p = .012$, *MD* = 2.2 %, but not stimulus incongruent trials, $t_{38} = -0.812$, $p = .849$, *MD* = 0.6 %, indicating an interference effect in multi-source and response interference trials. Also, the multi-source interference trials showed the greatest interference effect compared to the others (to response incongruent: $t_{38} = 4.036$, $p < .001$, *MD* = 2.8 %; stimulus incongruent: $t_{38} = 6.320$, $p < .001$, *MD* = 0.4 %). There was no significant difference between stimulus and response interference trials, $t_{38} = 2.284$, $p = .106$, *MD* = 1.6 %.

Picture-word interference task. The overall error rate in the picture-word interference task was too low (0.6%, while 4.4 % in the Experiment 1), so we did not further analyze the error rate data.

Reaction times

Multi-source interference task. The response times on the multi-source interference task showed a significant main effect of congruency type, $F(3, 152) = 34.593$, $p < .001$, $\eta_p^2 = 0.406$ (see Figure 5, left panel). The sample effect tests showed that the mean RT was faster in congruent trials compared to incongruent trials (multi-source: $t_{38} = -10.075$, $p < .001$, *MD* = 290 ms; response incongruent: $t_{38} = -3.973$, $p < .001$, *MD* = 114 ms; stimulus incongruent: $t_{38} = -5.396$, $p < .001$, *MD* = 155 ms), indicating an interference effect in multi-source, stimulus and response interference trials. Also, the multi-source interference trials showed the greatest interference effect comparted to the others (to response incongruent: $t_{38} = 6.102$, $p < .001$, *MD* = 176 ms; stimulus incongruent: $t_{38} = -5.396$, $p < .001$, *MD* = 155 ms). There was no significant difference between stimulus and response interference trials, $t_{49} = -1.423$, $p = .487$, *MD* = 41ms.

Picture-word interference task. The main effect of current congruency was also significant in the picture-word interference task, $F(1, 38) = 163.624$, $p < .001$, $\eta_p^2 = 0.812$, because the mean RT was slower on incongruent trials compared to congruent trials. The main effect of previous congruency was not significant, $F(3, 114) = 2.162$, $p = .096$, $\eta_p^2 = 0.054$, nor was the interaction between previous and current congruency, $F(3, 114) = 1.755$, $p = .160$, $\eta_p^2 = 0.044$. See Table 1 and 2 for more details.

Furthermore, three separate repeated measure 2 × 2 ANOVAs showed that there was a significant interaction when previous congruency only included congruent and response incongruent trials, $F(1, 38) = 5.507$, $p = .024$, $\eta_p^2 = 0.127$, because the congruency effect in the picture-word interference task was larger after response incongruent trials compared to congruent trials, indicating a reversed congruency sequence effect. There was no significant interaction when previous congruency only included congruent and multi-source interference trials, $F(1, 38) = 3.874$, $p = .056$, $\eta_p^2 = 0.093$, or congruent and stimulus incongruent trials, $F(1, 38) = 0.849$, $p = .363$, $\eta_p^2 = 0.022$. Together, the results indicating there was no cross-task congruency sequence effect across the two tasks, as shown in Figure 5, right panel.

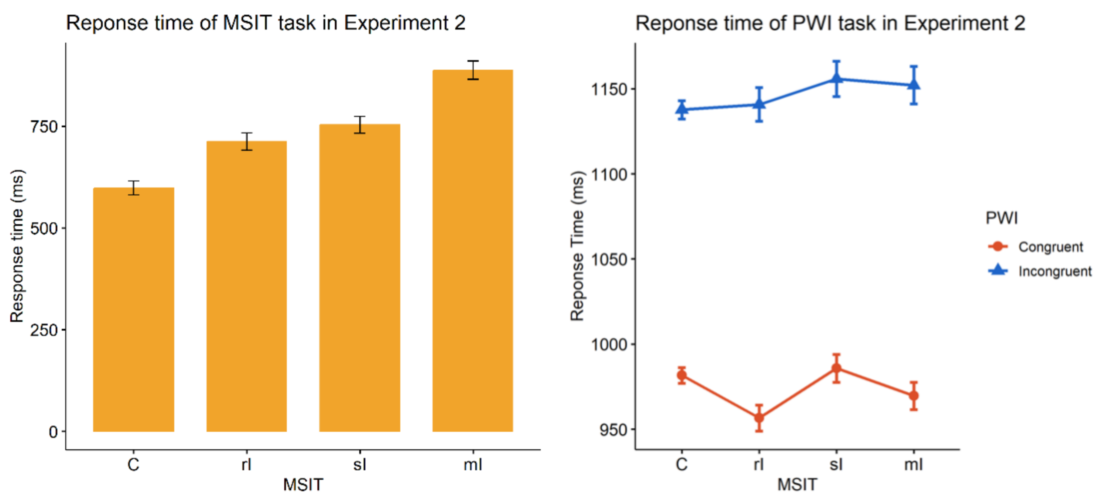

Figure 4. Mean response time as a function of multi-source interference task (C: congruent, sI: Stimulus Interference, rI: Response Interference, mI: Multi-source Interference) and picture-word interference task in Experiment 2. The error bars indicate standard error of the mean for each condition.

Combined Analysis

Cross-task CSE in the picture-word interference task

Because the two experiments were highly similar, a combined analysis was carried out to increase statistical power. Data from Experiments 1 and 2 were entered into a 2 (Experiment number: 1, 2) x 4 (previous congruency) x 2 (congruency) mixed-ANOVA ANOVA, with the factor "Experiment" being a between-subject factor. Also, we applied a Bayesian ANOVA to evaluate the evidence for the null hypothesis. To test the cross-task CSEs, we focused on reaction time from picture-word interference trials only as a function of the congruency conditions of the preceding multi-source interference trials.

The main effect of current congruency was significant in the picture-word interference task, $F(1, 86) = 365.531, p < .001, \eta_p^2 = 0.810$, because the mean RT was slower in incongruent trials compare to congruent trials. The main effect of previous congruency was not significant, $F(3, 258) = 1.076, p = .360, \eta_p^2 = 0.012$, nor was the interaction between previous and current congruency, $F(3, 258) = 1.792, p = .149, \eta_p^2 = 0.020$, BF_{01} =6.826, showing moderate evidence for the absence of an interaction. The main effect of Experiment was not significant, $F(1, 86) = 0.764, p = .384, \eta_p^2 = 0.009$, nor was the interaction between Experiment, previous and current congruency, $F(3, 258) = 0.625, p = .599, \eta_p^2 = 0.007$. See figure 5, left panel.

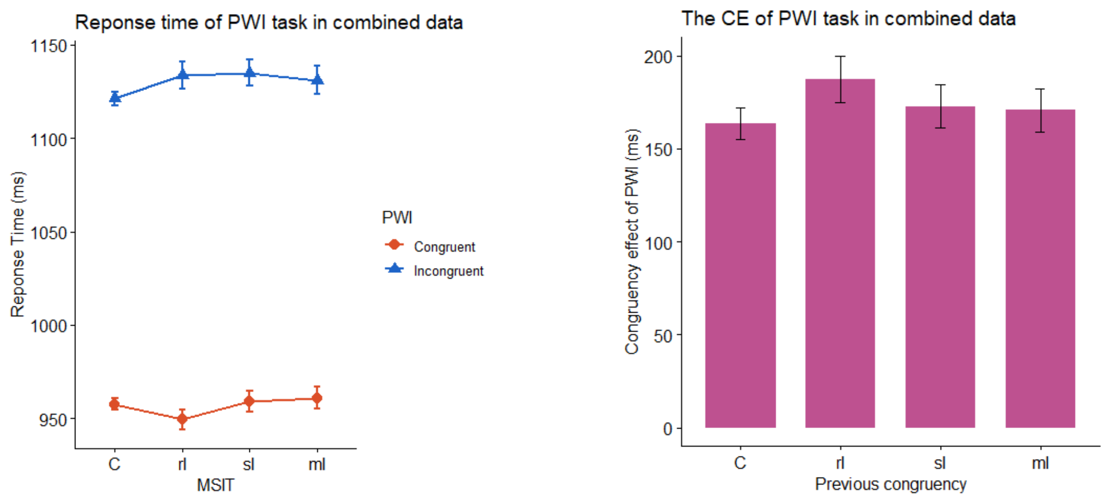

Figure 5. Left panel: Mean response time as a function of multi-source interference task (C: congruent, sI: Stimulus Interference, rI: Response Interference, mI: Multi-source Interference) and picture-word interference task in combined data. The error bars indicate standard error of the mean for each condition. Right panel: The congruency effect (reaction time) of picture-word interference task in combined data (CE: Congruency Effect). The error bars indicate standard error of the mean for each condition.

Furthermore, three separate repeated-measures 2 × 2 ANOVAs showed that there was a significant interaction when previous congruency only included congruent and response incongruent trials, $F(1, 86) = 6.039$, $p = .016$, $\eta_p^2 = 0.066$, because the congruency effect in picture-word interference task was larger after response incongruent than congruent trials, again suggesting a reversed congruency sequence effect (see figure 5, right panel, first blue bar). There was no significant interaction when previous congruency only included congruent and multi-source interference trials, $F(1, 86) = 0.091$, $p = .345$, $\eta_p^2 = 0.010$, see figure 5, right panel, last blue bar, or congruent and stimulus incongruent trials, $F(1, 86) = 0.932$, $p = .331$, $\eta_p^2 = 0.011$, see figure 5, right panel, second blue bar. Together, the results indicating there was no cross-task congruency sequence effect across the two tasks.

In order to further evaluate the evidence for the null hypothesis, we applied three separate one-tailed Bayesian Paired Samples T-Tests to compare the congruency effect of picture-word interference task after stimulus-, response- and multi-source incongruent trials to congruent trials. The results show strong evidence for the absence of congruency sequence effects (multi-source: $t_{87} = -0.783$, $p = .782$, $MD = 7.169$ ms, $BF_{01} = 14.260$; response incongruent: $t_{87} = -2.431$, $p = .991$, $MD = 23.941$ ms, $BF_{01} = 28.118$; stimulus incongruent: $t_{87} = -0.958$, $p = .83$, $MD = 9.275$ ms, $BF_{01} = 15.670$).

Within-task CSE in the picture-word interference task

We also tested the within-task CSEs in the PWI task. Data from Experiment 1 and 2 were combined and entered into a 2 (previous congruency) x 2 (current congruency) repeated-measures ANOVA. Due to the low error rate of Experiment 2 (0.6%), we only focused on the reaction time data.

The main effect of current congruency was significant, $F(1, 87) = 223.077$, $p < .001$, $\eta_p^2 = 0.823$, indicating a congruency effect (MD = 169ms). The main effect of previous congruency was not significant, $F(1, 87) = 0.362$, $p = .549$, $\eta_p^2 = 0.004$. Importantly, the two-way interaction was significant, $F(1, 87) = 13.150$, $p < .001$, $\eta_p^2 = 0.131$, MD = 25ms, indicating a within-task CSE in the PWI task, in the combined data.

Importantly, each two PWI trials were always separated by a trial from the multi-source interference task, which could have affected the within-task CSE of the picture-word interference task. Therefore, we also evaluated whether this within-task CSE was further modulated by the congruency type of the multi-source interference task. To this end, we ran a 2 (previous PWI: congruent, incongruent) * 4 (previous MSIT type: congruent, stimulus-interference, response-interference, multi-source-interference) * 2 (current PWI: congruent, incongruent) repeated-measures ANOVA on the combined data. The results again showed there was a significant within-task CSE: the 2-way interaction between previous congruency and current congruency of the picture-word interference task was significant, $F(1, 69) = 11.389$, $p = .001$, $\eta_p^2 = 0.142$. However, the three-way interaction was not significant, $F(1, 69) = 0.342$, $p = .774$, $\eta_p^2 = 0.005$, indicating that the within-task CSE of PWI task was not affected by the MSIT. Considering that this absence of a three-way interaction could be due to a power issue (as there were only few trials for each interference type of the multi-source interference task), we also ran a separate analysis where we combined the three interference conditions together as one incongruent condition, and ran a 2 (previous PWI: congruent, incongruent) * 2 (previous MSIT: congruent, incongruent) * 2 (current PWI: congruent, incongruent). The results, again, showed that the 3-way interaction was not significant, $F(1, 69) = 0.147$, $p = .703$, $\eta_p^2 = 0.002$, indicating the within-task CSE of PWI task was not affected by the MSIT.

Control Experiment: A within-task CSE in the multi-source interference task

Although we observed a significant within-task CSE in the picture-word interference task in Experiment 1, it was more difficult to evaluate a within-task CSE in the multi-source interference task due to the random but unbalanced sequence of the different congruency conditions. Moreover, we knew of no previous study that reported the CSE for the multi-source interference task. Therefore, we also conducted a control experiment to test the within-task CSE of the multi-source interference task.

Methods

Participants

Our aim was to collect a similar sample size as our main experiments. Forty-six participants were recruited from Ghent University and each participated in our study in exchange for 8 euros. Three participants were excluded because of poor performance (accuracy less than 60%). All remaining 43 participants (30 females; age range 18-34 years; mean age, 22.5 years) were native Dutch speakers and right-handed, reported normal or corrected-to-normal vision and no history of neurological disorders.

Task and Design

The stimuli and procedure were identical to the main experiments. However, the picture-word interference trials were replaced by the multi-source interference task, thus doubling the number of these trials for investigating the within-task CSE. We balanced the sequences of congruency conditions for each block, with equal number of pairs in the congruent-congruent, congruent-incongruent, incongruent-congruent and incongruent-incongruent conditions. Also, within the incongruent sequence conditions, the stimulus-, response- and multi-source-interference trials were balanced.

Analysis

The data pre-processing was identical to the main experiments. We excluded 1.04% of outliers from the reaction time analyses. After excluding trials following error trials, mean response times from all correct responses and mean error rates on the current multi-source interference task were entered into a 2 × 2 and a 4 × 4 repeated-measures ANOVA with factors "previous congruency" and "current congruency", with the 4 × 4 including the three different types of incongruency.

Results

Error rates

The overall error rate of current trials was 12%. The results of the 2 x 2 repeated-measures ANOVA showed a significant main effect of current congruency, $F(1, 42) = 36.578$, $p < .001$, $\eta_p^2 = 0.465$, indicating the interference effect. The main effect of previous congruency was also significant, $F(1, 42) = 6.391$, $p = .015$, $\eta_p^2 = 0.132$, showing that the error rate was significantly lower after incongruent compared to congruent trials. The interaction between previous congruency and current congruency was not significant, $F(1, 42) = 2.859$, $p = .098$, $\eta_p^2 = 0.064$, and thus did not support a within-task CSE in error rates. For the 4 x 4 repeated-measures ANOVA, our data did not meet the sphericity assumption (determined by the Maulchy test). We this applied the Greenhouse-Geisser correction. As before, there was a significant main effect of current congruency, $F(2.25, 76.48) = 27.373$, $p < .001$, $\eta_p^2 = 0.446$, as well as previous congruency, $F(1.97, 66.98) = 3.654$, $p = .032$, $\eta_p^2 = 0.097$, and a significant interaction between the two, $F(4.63, 157.42) = 3.165$, $p = .010$, $\eta_p^2 = 0.085$.

Therefore, we also ran three separate 2 by 2 repeated-measures ANOVA for each incongruent condition. Results showed significant two-way interactions for response and multi-source-interference, $Fs > 9.195$, $ps < .004$, $\eta_p^2 s > 0.203$, but not for stimulus interference, $F(1, 42) = 1.199$, $p = .280$, $\eta_p^2 = 0.028$ (see Table 3).

Table 3. Mean percentage of error rates (ER) in current MSIT task as function of previous MSIT task in Control Experiment.

	Previous			
MSIT	C	rI	sI	mI
C	3.5 (4.1)	2.9 (5.5)	2.3 (3.9)	4.8 (11.5)
rI	31.9 (35.2)	7.0 (9.7)	27.6 (37.0)	14.9 (22.1)
sI	6.8 (11.4)	8.9 (14.8)	8.0 (15.6)	6.3 (20.1)
mI	36.8 (33.5)	20.2 (26.5)	37.1 (34.2)	21.9 (28.0)

Note. Standard deviations are given in parentheses. C: congruent, sI: Stimulus Interference, rI: Response Interference, mI: Multi-source Interference

Reaction times

The mean reaction time of current trials was 588ms. The results of the 2 x 2 repeated-measures ANOVA, on the reaction times showed a significant main effect of current congruency, $F(1, 42) = 193.418$, $p < .001$, $\eta_p^2 = 0.822$, indicating the interference effect. The main effect of previous congruency was also significant, $F(1, 42) = 22.031$, $p < .001$, $\eta_p^2 = 0.344$, indicating the reaction time was lower after incongruent trials compare to the congruent trials. Importantly, the interaction between previous congruency and current congruency was also significant, $F(1, 42) = 4.987$, $p = .031$, $\eta_p^2 = 0.106$, indicating a within-task CSE in reaction times.

The results of the 4 x 4 repeated-measures ANOVA, conducted after applying the Greenhouse-Geisser correction, also showed a significant main effect of current congruency, $F(1.79, 53.81) = 189.128$, $p < .001$, $\eta_p^2 = 0.863$, a main effect of previous congruency, $F(2.32, 69.61) = 3.915$, $p = .019$, $\eta_p^2 = 0.115$, and a significant interaction between previous congruency and current congruency, $F(6.17, 185.11) = 2.365$, p

= .030, η_p^2= 0.073, indicating a within-task CSE in reaction times.

To follow-up we again ran three separate 2 by 2 repeated-measures ANOVA for each incongruent condition. Results show the two-way interactions of all of stimulus-, response and multi-source-interference conditions were significant, Fs > 5.024, ps < .030, η_p^2s > 0.109 (see Table 4).

Table 4. Mean reaction time (RT, in ms) in current MSIT task as function of previous MSIT task in Control Experiment.

	Previous			
MSIT	C	rI	sI	mI
C	502 (85)	525 (84)	523 (98)	549 (101)
rI	596 (85)	578 (106)	622 (95)	637 (125)
sI	636 (117)	671 (121)	628 (112)	672 (112)
mI	767 (138)	775 (133)	779 (151)	764 (129)

Note. Standard deviations are given in parentheses. C: congruent, sI: Stimulus Interference, rI: Response Interference, mI: Multi-source Interference

Discussion

In the present study, our aim was to test whether we could observe a cross-task CSE when using two tasks with little representational overlap. Based on the U-shaped function hypothesis, we anticipated that a cross-task CSE would be observed between two distinct tasks that rely on non-overlapping stimulus and response representations. To investigate this, we interleaved a manual multi-source interference task and a vocal picture-word interference task. The advantage of this design over previous studies was that the multi-source interference task allowed us to test CSE separately for stimulus- and response-level conflict, in case that the level of conflict (e.g., Frühholz et al., 2011) was a determining factor in cross-task CSE transfer. However, across two experiments, the results did not show any evidence for a cross-task CSE.

Our study was set up as a direct evaluation of the U-shaped hypothesis (Braem et al., 2014), and extension of previous studies (e.g., Kan et al., 2013), both suggesting cross-task CSEs can be observed, when the stimuli and response modes of both tasks are different. Therefore, also in our study, we deliberately chose tasks that were highly dissimilar. Specifically, we used different task domains, different stimulus types and identity, different response mode and identity, and different task-relevant dimensions. Using such tasks, we assumed task representations with such high dissimilarity can be activated simultaneously in working memory, and, therefore, a cross-task CSE could be observed when strengthening all active task representations after conflict (e.g., Verguts & Notebaert, 2008). However, no cross-task CSE was observed. Instead, our results align with the concept of task- or conflict-specific conflict adaptation (e.g., Egner, 2008; Nozari & Novick, 2017) and previous studies that also used the picture-word interference task, interleaved with a prime-probe task or a sentence processing task (Freund & Nozari, 2018).

Interestingly, our findings seemingly contradict other studies showing cross-task CSEs between cognitive tasks and linguistic tasks (Hsu et al., 2021; Hsu & Novick, 2016; Kan et al., 2013; Ovans et al., 2022; Thothathiri et al., 2018). However, it is worth noting that these studies only involved language comprehension, while our study focused on language production. From a linguistic perspective, there is a significant difference between language production and language comprehension. Language production requires a stronger commitment to selecting a specific representation for action than does language comprehension (Nozari, 2018; Nozari & Novick, 2017; Nozari & Pinet, 2020) and is thus more cognitively demanding. When considering the original motivation for the U-shaped hypothesis put forward by Braem and colleagues (2014), it may be easier to simultaneously keep active two tasks when one (or both) of them has low cognitive demands. Potentially, this difference may explain why we have not been able to observe the cross-task CSE in our design where, despite using two tasks with relatively straightforward and arguably trained response mappings.

Another potential reason for the absence of a cross-task CSE could be that the multi-source interference task and the picture-word interference task are less dissimilar than we had assumed. For one, they both shared the same sensory mode (visual), and thus required paying close visual attention to the screen. This shared sensory mode might have created interference, making it more challenging for individuals to simultaneously maintain both task representations, thereby preventing the CSE from occurring across tasks. A possible solution could involve using a cognitive task with an auditory mode (e.g., an auditory Simon task) in combination with a visual task from a different domain (e.g., a picture-word interference task). However, at the same time, we note that several of the tasks mentioned above that did find cross-task CSEs (Hsu et al., 2021; Hsu & Novick, 2016; Kan et al., 2013; Ovans et al., 2022; Thothathiri et al., 2018) similarly used tasks that both required paying visual attention, making this alternative explanation less likely.

Another finding in our study was the observation of a reversed CSE when the previous trials only involved response-interference trials. While we should be careful with overinterpreting this effect, as it was only observed after one of the three possible interference conditions in the multi-source interference task, this effect can be explained by the adaptation-by-binding model (Verguts & Notebaert, 2008, 2009), which posits that the strengthening of active network weights between control representations and different task sets through Hebbian learning has a relative inverse effect on non-active weights. Note that such reversed cross-task CSE has been reported in several previous studies (Braem et al., 2011; Brown et al., 2007; Cracco et al., 2022; Freund & Nozari, 2018; Notebaert & Verguts, 2008; Scherbaum et al., 2011, 2016). The observation of the reversed CSE in the response-interference condition, although not predicted a priori, is compatible with our view that production requires commitment. The closer one gets to articulation, the stronger this commitment. For example, one could simultaneously entertain both "sofa" and "couch" as labels for a picture, but when selecting an articulatory-phonetic representations, one must commit to one of the two. This means that conflict resolution at the response level requires a stronger commitment, which, in turn, implies stronger adaptation —and consequently reversed adaptation— effects at the response, compared to the stimulus, level.

Finally, there is an alternative explanation that fits the current study. While accumulating evidence on the longevity of CSE (e.g., Freund & Nozari, 2018; Schiltenwolf, Kiesel, & Dignath, 2023) is evidence that the effect is mediated through some sort of a learning mechanism, the nature of this mechanism is less clear. The U-shaped hypothesis is based on Hebbian learning, which allows for incidental strengthening of connections that are active but not the target of the task. In contrast, error-based learning is a more focused form of learning, in which only those connections that are directly relevant to the task goal are strengthened. Both types of learning predict a positive within-task CSE. Both also explain the reversed CSE observed across tasks. However, the error-based learning account, unlike the Hebbian learning account, does not predict any positive cross-task CSE for tasks without representational overlap. Therefore, if error-based learning is the key mechanism underlying CSEs, the empirical pattern of results should be precisely as reported here, as well as past studies (e.g., Braem et al., 2011; Brown et al., 2007; Cracco et al., 2022; Freund & Nozari, 2018; Notebaert & Verguts, 2008; Scherbaum et al., 2011, 2016).

It is worth noting that Hebbian and error-based learning mechanisms are not mutually exclusive. In fact, it is not unreasonable to assume that learning may have both a task-focused and an incidental component. This mix could explain the pattern of the empirical results in the broader literature. In most situations, when an action is to be performed, e.g., naming pictures, learning is more strongly task-focused, i.e., error-based learning. As such, experiments that have involved action-based tasks often do not find evidence of cross-task CSE. In contrast, tasks that do not require a strong commitment to a response, e.g., passive language comprehension, may involve incidental learning mechanisms, i.e., Hebbian learning, which could lead to some degree of cross-task CSE, as predicted by the U-shaped hypothesis.

However, it is important to understand the limitations of this generalization. While incidental learning can provide some benefit to the other task, the incidental nature of such benefit makes it relatively weak. Moreover, this weak positive CSE can easily be foreshadowed by the negative (reversed) CSE in case of response conflict. This conclusion is very important for clinical purposes, as it implies that cognitive enhancement by training tasks with little representational overlap is not expected to be effective (e.g., Melby-Lervåg et al., 2013; Simons et al., 2016; Von Bastian et al., 2023).

As we predicted, we found robust within-task CSEs in the picture-word interference task in the combined data, as well as in the multi-source interference task in the control experiment. These findings are consistent with previous observations in the literature, for example, the CSE in the picture-word interference task has been documented before in both behavioral and EEG studies (Freund & Nozari, 2018; Shitova et al., 2017). While no previous study has examined the CSE within the multi-source interference task, the within-task CSE has been observed in highly similar stimulus and response conflict tasks, such as the Flanker conflict task and Simon conflict task (Dignath & Kiesel, 2021; Lee & Cho , 2023).

In conclusion, the present study aimed to investigate the existence of a cross-task CSE between considerably distinct tasks using different stimulus and response representations, as a direct test of the inverted-U hypothesis which states that highly dissimilar tasks can be co-activated and benefit from domain-general conflict adaptation processes (Braem et al., 2014), and conceptual replication of earlier work that did show cross-task CSE. However, our results do not support these predictions or previous results. Instead, they offer support for theories on task-specific adaptive control in conflict tasks. Therefore, we believe future work should aim to set up more systematic comparisons between studies that do and do not show cross-task CSEs (see also, Zhu et al., 2024), to unravel what determines its task specificity and inform contemporary theories of adaptive control.

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