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Short-term pre-exposure to modality mappings: Modality-incompatible single-task exposure reduces modality-specific between-task crosstalk in task-switching☆

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ABSTRACT

Modality compatibility refers to the similarity of the stimulus modality and the modality of the sensory-response effect that the response produces (i.e., vocal responses produce auditory effects). In this study, we investigated the effect of short-term pre-exposure of modality compatibility in task-switching. To this end, participants were exposed to either modality-compatible (visual-manual and auditory-vocal) or modality-incompatible (visual-vocal and auditory-manual) single-tasks. After a short-term single-task pre-exposure (with either both modality-compatible tasks, 2 × 80 trials each, or both modality-incompatible tasks, 2 × 80 trials each), participants were transferred to a task-switching situation, where they switched between tasks in both a modality-compatible and an incompatible condition. We found that after pre-exposure to modality-compatible single-tasks the typical effect of modality compatibility was found (i.e., larger switch costs with modality-incompatible tasks compared to modality-compatible tasks). In contrast, after pre-exposed to modality-incompatible single-tasks, modality compatibility no longer influenced switch costs. We assume that long-term modality-compatible associations could be overridden by short-term, task-specific associations to reduce between-task crosstalk.

1. Introduction

Multitasking is costly, but these costs strongly depend on the specific situation and the related required motor action. Two lines of research investigate the source of multitasking costs, the dual-task research, where two tasks have to be performed simultaneously, and the task-switching research, where tasks are performed sequentially (Kiesel et al., 2010; Koch, Poljac, Müller, & Kiesel, 2018; Vandierendonck, Liefooghe, & Verbruggen, 2010, for a review). Performance decrements were found for dual tasks (i.e., simultaneously performed tasks compared to single-tasks — *dual-task costs*) and for task-switching (i.e., task switches compared to task repetitions — *switch costs*). These multitasking costs were explained by limitations in central processing, referring to the notion of separate sequentially aligned cognitive processing stages (e.g., Pashler, 1994; Marois & Ivanoff, 2005; see Sanders, 1998, for a review). It was commonly assumed that these central cognitive processes intervene between sensory and motor processes content-independently during decision and response-selection (e.g., Johnson & Proctor, 2004). However, studies in both lines of research showed that the degree of the observed task interference (i.e., dual-task costs and switch costs) is determined at least partly by the specific mappings of the sensory stimulus modality to the modality of the required motor response, arguing against the idea of completely content-independent stimulus-response translation process (e.g., Hazeltine & Schumacher, 2016; Huestegge & Hazeltine, 2011; see also Koch et al., 2018, for a review). Instead these modality mapping effects underline the importance of the interaction between cognition on the one hand and the initiation of motor processes during response-selection. To understand this interaction better, the notion of "ideo-motor" processing represents a highly useful framework.

Any motor action is performed to achieve a certain effect. Guided by this basic idea the ideomotor theory was developed stating that actions are preceded and guided by the anticipation of their sensory consequences (Badets, Koch, & Philipp, 2016; Greenwald, 1972; also see e.g., Shin, Proctor, & Capaldi, 2010). More specifically, it is assumed that a stimulus is compatible to a response to the degree that a stimulus

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resembles the anticipated response effect (e.g., saying "A" in a response to hearing the letter "a") (see e.g., Greenwald, 1972). Please note that the concept of ideomotor compatibility requires a match both between modality levels and between the perceptual and/or conceptual identity of the stimulus and the anticipated "response image" (Greenwald, 1970).

More generally, the stimulus-response modality combinations were investigated in both dual-task paradigms (Göthe, Oberauer, & Kliegl, 2016; Hazeltine, Ruthruff, & Remington, 2006; Levy & Pashler, 2001; Stelzel, Schumacher, Schubert, & D'Esposito, 2006) and in task-switching paradigms (Fintor, Stephan, & Koch, 2018, 2019; Schacherer & Hazeltine, 2019; Schaeffner, Koch, & Philipp, 2018; Stephan, Josten, Friedgen, & Koch, 2021; Stephan & Koch, 2010, 2011, 2016). As an example, Hazeltine et al. (2006) found reduced dual-task costs in the condition with visual-manual (VM) and auditory-vocal (AV) tasks relative to the condition with visual-vocal (VV) and auditory-manual (AM) tasks. Consistent with the findings in the dual-task paradigm, Stephan and Koch (2010) found smaller switch costs when switching between VM and AV tasks compared to VV and AM tasks.

Stephan and Koch (2011) proposed the modality-compatibility account to explain the effect of modality compatibility in task switching. Modality compatibility refers to the similarity between the stimulus modality and the modality of the anticipated response-related sensory consequences. The authors assumed that there is a special linkage between stimuli and responses derived from (life-long) action-effect learning experiences to bind certain stimulus modalities to the most salient response effects (e.g., eye-hand coordination usually results in visible effects — VM task, and speaking leads to auditory effects — AV task). Extrapolating the concept of ideomotor compatibility, they claim that actions are coded by the representations of anticipated response effects (e.g., Greenwald, 1972; Kunde, Elsner, & Kiesel, 2007; see Badets et al., 2016; Shin et al., 2010, for reviews). Accordingly, anticipating visual feedback to manual responses, for instance, primes processing of visual stimuli. Importantly, when switching between modality-compatible tasks, the sensory-response effects and the stimulus-induced activation prime each other on the modality level, whereas switching between modality-incompatible tasks evokes between-task crosstalk because the modality of the anticipated sensory-response effect in one task refers to the stimulus modality of the competing task (Fintor et al., 2018, 2019; Schacherer & Hazeltine, 2019; Schacherer & Hazeltine, 2021; Schaeffner et al., 2018; Stephan & Koch, 2010, 2011, 2016).

Investigating modality compatibility is relevant for theoretical accounts of structural mechanisms of human multitasking explaining between-task crosstalk. Specifically, assuming ideomotor learning processes as explanation for the modality-specific effects brings together accounts in terms of cognitive structure and plasticity (Koch et al., 2018, for an overview). Research on plasticity investigates the question of how practice changes the organisation of cognitive processes (e.g., Liepelt, Fischer et al., 2011; Liepelt, Strobach, et al., 2011; Ruthruff, Van Selst, Johnston, & Remington, 2006; Schumacher, Seymour, Glass, Kieras, & Meyer, 2001; Strobach, Liepelt, Schubert, & Kiesel, 2012; Yeung & Monsell, 2003). Based on the idea that the effect of modality compatibility derives from ideomotor action-effect learning, this effect should strongly depend on learning and experience and thus display evidence for plasticity.

However, results are mixed and research is restricted to dual-task situations. In a study by Schumacher et al. (2001), for example, participants practiced VM and AV (i.e., modality-compatible) tasks, and after five extensive practice sessions, they found a near elimination of dual-task costs, assuming perfect time sharing by the end of training. Later, several studies extended the findings of Schumacher et al. (2001). In comparison, Liepelt, Fischer et al. (2011) replicated Schumacher et al.'s (2001) finding of practice reducing dual-task costs, but residual costs still remained, even when replacing the AV task with an auditory-pedal (AP) task. Liepelt, Strobach et al. (2011) argued that extensive practice improves intertask coordination skills, which could be observed by a reduction of dual-task costs. They had participants either practice only single-tasks (AV and VM tasks) or both single-tasks and dual-tasks, and found that when transferred into a new dual-task situation the latter group showed an increased dual-task benefit relative to the single-task practice group. However, dual-task practice might improve the skill to optimize scheduling of two simultaneously presented tasks, but performance in task-switching could not be perfectly optimized (Strobach et al., 2012). In a task-switching study by Strobach et al. (2012), participants performed either a VM and an AV task or a VM and an AM task, and even after seven practice sessions, they reported persisting switch costs. None of these studies systematically assessed modality compatibility directly and in the context of practice.

In contrast, for example, Hazeltine et al. (2006) and Göthe et al. (2016) manipulated modality compatibility and had participants practice either VM and AV (i.e., modality-compatible) tasks or VV and AM (i.e., modality-incompatible) tasks in a dual-task paradigm.[1] Overall, both studies demonstrated that even after extensive practice, the difference in dual-task costs between VV and AM tasks compared to VM and AV tasks remained. However, in groups with compatible feature pairings (i.e., verbal stimulus features mapped to verbal responses or spatial stimulus features mapped to spatially separated response keys), dual costs were reduced for both modality pairings. It was argued that after practice only the compatible feature pairings enabled crosstalk-free, parallel processing.

Note, however, that the studies mentioned above employed the dual-task paradigm, which differs from the task-switching paradigm in a number of methodological aspects. Moreover, the practice sessions were rather extensive (see e.g., Hazeltine et al., 2006). However, from compatibility research, we know that even short-term practice of an incompatible spatial mapping can reduce or even reverse spatial compatibility effects. One example refers to the so-called Simon effect, which is the finding that performance is better when the stimulus is presented at the same location as the response even if the stimulus location is irrelevant for the task (Proctor & Lu, 1999; Proctor, Marble, & Vu, 2000). Accounts explaining the Simon effect usually distinguish between short- and long-term associations. Short-term associations refer to the specific rule between the relevant stimulus and the corresponding response defined by the instruction, whereas long-term associations are overlearned and activated automatically (see, e.g., Zorzi & Umiltà, 1995). Studies observed a reduced or even reversed Simon effect after practice with the incompatible mapping, suggesting that the effect is due to short-term associations rather than a modification of long-term associations (see e.g., Proctor & Lu, 1999).

Based on such evidence in compatibility research, we similarly assume that practicing modality-incompatible single-tasks would strengthened short-term modality-incompatible associations in working memory (WM), consequently reducing the modality-compatibility effect. In contrast, practicing modality-compatible single-tasks should not lead to such a reduction since modality-compatible tasks are assumed to be defined by long-term associations in the first place.

Particularly in task switching, there is evidence that even moderate pre-training could reverse dominance relations across tasks (Yeung & Monsell, 2003). In the study of Yeung and Monsell (2003), the relative strength across a task pair was manipulated by selectively practicing one of the tasks and larger switch costs were found for switching to the recently practiced, stronger task. Also, in the present study, the modality-incompatible and modality-compatible tasks were equal in relative strength as demonstrated in previous studies that did not find difference in single-task performance (Stephan et al., 2021; Stephan & Koch, 2010, 2011, 2016). Thus, the modality-compatibility effect does not represent differences in general task difficulty per se but rather

[1] In addition, feature pairings were manipulated (for further explanation please see Goethe et al., 2016).

represent compatibility relations *across* tasks. Please note that these tasks were highly spatially S-R compatible tasks, which should additionally render it unnecessary to practice these tasks extensively but keep practice at a moderate level.

Hence, in contrast to previous dual-task studies (e.g., Hazeltine et al., 2006), we employed a more limited practice schedule (4 × 80 trials) using single-task conditions with either modality-compatible (VM, AV) or modality-incompatible (VV, AM) single tasks to see if even short-term single-task practice can affect switch costs in a subsequent task-switching phase. Because of the comparatively smaller number of practice trials, we term our manipulation “short-term pre-exposure” (in the following also referred to as pre-exposure).

Specifically, we expected a reduction of the influence of modality compatibility on switch costs after being exposed to modality-incompatible single tasks compared to modality-compatible single tasks. Based on the effect of modality compatibility, the representation of the anticipated response-effect and the stimulus-induced activation prime each other, resulting in reduced between-task crosstalk with modality-compatible tasks. Since modality-compatible mappings are presumably acquired from long-term learning experiences, being exposed to these mappings should not result in an additional reduction of the modality-compatibility effect on switch costs. In contrast, switching between modality-incompatible tasks causes increased between-task crosstalk because the anticipated response-effect primes processing of the competing task (i.e., from the modality-compatible task). Accordingly, being pre-exposed to modality-incompatible tasks might create short-term associations in working memory (WM). These short-term associations could strengthen the mental representation of the modality-incompatible tasks (i.e., their task sets) and shield them against the disruptive influence of the anticipated response effects associated with the competing task. More specifically, the short-term pre-exposure might inhibit the anticipation of the modality-compatible response-effect and a short-term association between modality-incompatible stimuli and response might form, resulting in decreased between-task crosstalk.

2. Method

2.1. Participants

Forty-eight participants (38 women, 46 right-handed; $M = 22.40$ years; $SD = 2.97$) with normal or corrected-to-normal vision took part in the experiment. Twenty-four participants were randomly assigned to the modality-incompatible single-tasks pre-exposure group (18 women; 24 right-handed; $M = 22.21$ years; $SD = 3.30$). The other half of the participants was assigned to the modality-compatible single-tasks pre-exposure group (20 women; 22 right-handed; $M = 22.52$ years; $SD = 2.67$). All participants were University students who gave their informed consent.

2.2. Stimuli, task and apparatus

The visual stimulus was a black diamond on a white background with a width and height of 1.5 cm, presented either 1.25 cm to the left or right of the center. Viewing distance was approximately 60 cm. The auditory stimulus was a 400 Hz tone presented via headphones to the left or to the right ear. Stimuli were unimodal (i.e., either visual or auditory). Participants performed a spatial discrimination task by indicating the location of the visual or auditory stimulus. Manual responses were given by pressing the 4 or the 6 key on the numerical keyboard with the left or right index finger, respectively. Vocal responses were given by saying the German words “links” (left) or “rechts” (right). Response time (i.e., speech onset) of vocal responses was measured using a voice key. Accuracy of the vocal responses was coded online by the experimenter during the inter-trial interval. The S-R mapping was spatially compatible. The apparatus was equipped with a 15-in. display (LG Flatron L1710B), a microphone, headphones (Grundig GH629), and with a QWERTZ computer keyboard.

2.3. Procedure

Written instructions appeared on the screen and the experimenter explained the task orally before the experiment. Participants were asked to respond quickly and accurately. Participants started with the short-term pre-exposure phase followed by the task-switching phase. Half of the participants were exposed to the modality-compatible pre-exposure, whereas the other half was exposed to the modality-incompatible pre-exposure). With modality-compatible pre-exposure, subjects performed two single task blocks (at 80 trials) of the AV task and two single task blocks (at 80 trials) of the VM task. With modality-incompatible pre-exposure, subjects performed two single task blocks (at 80 trials) of the AM task and two single task blocks (at 80 trials) of the VV task. The task order was counterbalanced across the participants. After pre-exposure, each participant took part in a transfer phase using both modality-compatible and modality-incompatible task-switching blocks (counterbalanced order). The task-switching blocks contained four practice trials and 48 experimental trials in both the modality-compatible and modality-incompatible conditions. Task-switching conditions contained fewer trials than previous studies on modality-compatibility research in task-switching (160 trials in both conditions; e.g., Stephan & Koch, 2010, 2011) in order to investigate the effect of pre-exposure of single-task practice on task switching and to avoid possible counteracting after-effects like overwriting a short-lived pre-exposure effect due to longer task-switching bocks.

Each trial started with the onset of the stimulus and lasted until a response was made or until 1500 ms had elapsed. The response-stimulus interval (RSI) was 600 ms. If an error was made by the participant, the German word "Fehler" (error) was presented for 500 ms (lengthening the RSI to 1100 ms). The experiment took about 50 min.

2.4. Design

The independent within-subject variables were modality compatibility (incompatible vs. compatible) and task transition (switch vs. repetition); the independent between-subject variable was pre-exposure type (modality-compatible vs. modality-incompatible). The dependent variables were response time (RT) and error rate (PE). All significance tests were conducted with an alpha level of 0.05. Raw data are available at https://osf.io/4w3zg/?view_only=ef53142557de45ad928c20c5e3343ba2.

3. Results

The first two experimental trials of each block were discarded from analysis. Vocal RTs below 50 ms were excluded as voice-key artefacts (1.4%). For RT analysis, RTs were Z-transformed for each subject separately and then values exceeding ±3 were eliminated as outliers (1.5%). In addition, error trials and trials following error trials were excluded (9.8%). For all following analysis, mean RTs and PEs were collapsed across the two modality-incompatible tasks and across the two modality-compatible tasks, respectively. Like in previous studies (e.g., Friedgen et al., 2020; Stephan & Koch, 2010, 2011, 2015, 2016; Stephan et al., 2013; Stephan et al., 2021), this allows to equate all trivial differences pertaining to differences in stimulus modality and response modality per se (e.g., vocal responses are typically slower than manual responses). According to our definition of modality compatibility in terms of the interaction of stimulus modality and response modality, this analysis yields comparable modality-compatibility conditions, in which exactly the same stimuli and responses occurred in both conditions (see Stephan & Koch, 2010).

3.1. Single task performance during short-term pre-exposure

To investigate whether there was a difference between the two pre-exposure single task conditions, we conducted an independent samples *t*-test. The analysis indicated no significant difference between performance in modality-compatible and modality-incompatible single-tasks, neither for RT, $t(46) = 1.075$, $p = 0.288$, nor PE, $t(46) = 1.075$, $p = 0.288$. This is in line with previous findings (see e.g., Stephan & Koch, 2010, 2011).

3.2. Task-switching performance

To investigate the modality-compatibility effect in task-switching after short-term pre-exposure, we conducted an ANOVA with the independent within-subject variables modality compatibility and task transition, as well as with pre-exposure type as a between-subject variable, on RT and PE (see Tables 1, 2; Fig. 1). The main effect of task transition was significant for RT, $F(1, 46) = 31.326$, $p < 0.001$, $n^2_p = 0.405$, showing higher RTs on switch trials compared to repetition trials (501 ms vs. 464 ms) and it did not differ between pre-exposure types, $F < 1$ for the interaction of pre-exposure and task transition. The main effect of pre-exposure (i.e., group) was significant neither for RT, $F(1, 46) = 2.844$, $p = 0.098$, $n^2_p = 0.058$ (502 ms vs. 406 ms) for modality compatible compared to incompatible pre-exposure nor PE, $F(1, 46) = 2.533$, $p = 0.118$, $n^2_p = 0.052$ (6.9% vs. 5.1% for modality compatible compared to incompatible pre-exposure). The main effect task transition and its interaction with pre-exposure was not significant for PE, *F*s < 1. Please note that the non-significance of the main effect of pre-exposure might be due to a lack of power. However, considering a possible difference between the pre-exposure groups would refer to the basic performance level and thus cannot account for differential influence of pre-exposure on modality compatibility on switch costs (i.e., the three-way interaction, see below).

Overall, the RTs were higher with modality-incompatible tasks than with modality-compatible tasks, $F(1, 46) = 19.465$, $p < 0.001$, $n^2_p = 0.297$ (502 ms vs. 462 ms), but this effect was not significant for PE, $F(1, 46) = 1.615$, $p = 0.210$, $n^2_p = 0.297$. The interaction with modality compatibility and task transition was significant neither for RT, $F(1, 46) = 1.950$, $p = 0.169$, $n^2_p = 0.041$, nor PE, $F < 1$. The interaction of modality compatibility and pre-exposure was not significant for RT, $F(1, 46) = 2.568$, $p = 0.116$, $n^2_p = 0.053$, nor PE, $F < 1$. The remaining two-way interactions were also not significant, *F*s < 1. Please note that the non-significance of the interactions between modality compatibility and task transition as well as between modality compatibility and pre-exposure might be due to a lack of power. However, even if these effects and interactions would be significant, they would be qualified by the significant three-way interaction including these three variables, RT, $F(1, 46) = 4.530$, $p = 0.039$, $n^2_p = 0.090$.[2] (For PE, the three-way interaction was not significant, $F < 1$.) To follow up the significant three-way interaction on RT, we conducted an ANOVA separately for both pre-exposure types (see Fig. 1).

In both pre-exposure groups, the main effect of task transition [modality-compatible pre-exposure: $F(1,23) = 17.752$, $p < 0.001$, $n^2_p = 0.436$; modality-incompatible pre-exposure: $F(1, 23) = 13.581$, $p < 0.001$, $n^2_p = 371$] and modality compatibility [modality-compatible pre-exposure: $F(1, 23) = 13.690$, $p = 0.001$, $n^2_p = 0.373$; modality-incompatible pre-exposure: $F(1, 23) = 5.814$, $p = 0.024$, $n^2_p = 0.202$] was significant. After modality-compatible pre-exposure, we found the expected higher switch costs with modality-incompatible compared to modality-compatible mappings (58 ms vs. 25 ms), $F(1, 23) = 4.854$, $p < 0.05$, $n^2_p = 0.174$. However, after pre-exposure to modality-incompatible mappings, this influence disappeared (and was numerically even reversed, 29 ms vs, 36 ms), $F < 1$.

Taken together, we found that the single-task performance did not differ between the short-term pre-exposure groups. Overall, there was a main effect of modality compatibility. Please note that the non-significant main effect of pre-exposure and the interaction between modality compatibility and pre-exposure might be due to a lack of power. However, our interpretation does not rely on these effects being non-significant but rather it would strengthen the argument. Nevertheless, we refrain from any further speculation at this point, as further studies with a larger sample size are necessary. The modality-compatibility effect in the subsequent task-switching phase remained after being pre-exposed to modality-compatible single-tasks. Importantly, we demonstrated that being pre-exposed to modality-incompatible single-tasks abolished the modality-compatibility effect on switch costs in task switching, indicating that modality-incompatible single-task pre-exposure transferred to task-switching performance to reduce between-task crosstalk while overall switch costs remained.

4. General discussion

The aim of the present study was to examine the influence of pre-exposure on modality-compatibility effects in task switching. To this end, two groups of participants were pre-exposed either to modality-compatible or to modality-incompatible single tasks before they switched between tasks in both compatibility conditions (i.e., the modality-compatible and the modality-incompatible condition, in counterbalanced order).

During the single-task pre-exposure preceding the task-switching phase, we found no general performance differences between the two pre-exposure groups, indicating equally fast and accurate performance in modality-compatible and modality-incompatible tasks as long as there was no switching requirement. This is consistent with previous studies of Stephan and Koch (2010, 2011), who observed no consistent modality-compatibility effect in single-task performance, suggesting that the influence of modality compatibility is a between-task phenomenon that arises only when switching between tasks.

Importantly, we found an effect of short-term pre-exposure on modality-compatibility effects in task-switching. After being exposed to modality-compatible single-tasks, modality compatibility still influenced task-switching, showing larger switch costs with modality-incompatible tasks relative to modality-compatible tasks, whereas after being exposed to modality-incompatible single-tasks, the influence of modality compatibility on switch costs was reduced, even though a general slowing due to modality incompatibility remained.

Studies investigating practice effects by using tasks with different modalities found strong performance improvement after practice (e.g., Liepelt, Fischer, et al., 2011; Strobach et al., 2012), but these studies did not isolate the effect of modality compatibility. In contrast, results of studies on the modality compatibility effect did not show this clear data pattern (see e.g., Göthe et al., 2016; Hazeltine et al., 2006) and were restricted to the dual-task paradigm. Thus, our present study contributes to and extends this field of research by investigating the effect of short-term pre-exposure on modality compatibility in task switching.

Generally, practice-related changes in cognitive processes were explained by task integration (e.g., Hirst, Spelke, Reaves, Calharack, & Neisser, 1980; Liepelt, Strobach et al., 2011), task automatization (e.g., Maquestiaux, Lague-Beauvais, Ruthruff, & Bherer, 2008; Schumacher et al., 2001), or shortening of processing stage duration (Ruthruff et al., 2006). For instance, the idea of task automatization predicts no or at least very small interference between tasks because automatized tasks

[2] To see how likely it was to find a significant three-way interaction of modality compatibility, task transition and pre-exposure, we ran a post-hoc power analysis based on the mean RTs. A Monte Carlo Simulation of a 2 × 2 × 2 repeated measurements ANOVA with sample size, means, standard deviations and correlations based on the data of the experiment was conducted in R. The simulation was run 1000 times and the significant interaction was present in a total of 91.1% of the runs. This suggests that the three-way interaction represents a robust finding.

Table 1
Mean response times (RT) as a function of pre-exposure, modality compatibility and task transition (single, repetition vs. switch), (standard errors in parenthesis).

Stimulus modality	Modality-compatible exposure						Modality-incompatible exposure					
	Response modality						Response modality					
	Vocal			Manual			Vocal			Manual		
	Single	Repetition	Switch	Single	Repetition	Switch	Single	Repetition	Switch	Single	Repetition	Switch
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Visual		450 (27)	552 (28)	**266(4)**	**375 (19)**	**394 (14)**	347 (12)	450 (23)	485 (21)		**354 (14)**	**405 (14)**
Auditory	**461 (18)**	**551 (22)**	**582 (19)**		550 (26)	565 (26)		**509 (23)**	**530 (19)**	345 (18)	470 (18)	493 (21)

Modality represents the interaction of stimulus modality (visual vs. auditory) and response modality (vocal vs. manual); bold values depict the modality-compatible condition, single represents practice performance.

Table 2
Percent error (PE) as a function of pre-exposure, modality compatibility and task transition (single, repetition vs. switch), (standard errors in parenthesis).

Stimulus modality	Modality-compatible exposure						Modality-incompatible exposure					
	Response modality						Response modality					
	Vocal			Manual			Vocal			Manual		
	Single	Repetition	Switch	Single	Repetition	Switch	Single	Repetition	Switch	Single	Repetition	Switch
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Visual		13.9 (3.8)	15.5 (2.3)	**2.0 (0.6)**	**0.8 (0.8)**	**0.7 (0.5)**	5.9 (1.0)	12.1 (2.7)	9.5 (1.7)		**0.5 (0.5)**	**0.3 (0.3)**
Auditory	**4.6 (0.5)**	**12.3 (3.2)**	**10.3 (1.9)**		0.7 (0.7)	0.6 (0.6)		**9.9 (2.9)**	**8.6 (1.2)**	2.4 (0.4)	0.0 (0.0)	0.3 (0.3)

Modality represents the interaction of stimulus modality (visual vs. auditory) and response modality (vocal vs. manual); bold values depict the modality-compatible condition, single represents practice performance.

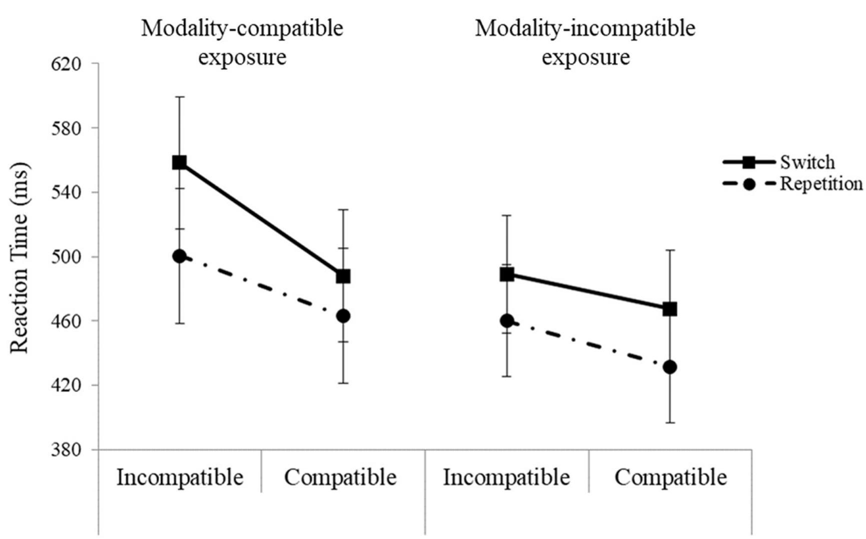

Fig. 1. Mean reaction times as a function of practice group and modality compatibility. Error bars represents 95% confidence interval of the mean.

could be processed and performed without the limited central processing stages. However, our finding of reduced between-task crosstalk after being pre-exposed to modality-incompatible single-tasks is very unlikely to be explained by increased automatization in processing because a recent study suggested that task automatization is possible only with modality-compatible tasks but not with modality-incompatible tasks (see Maquestiaux, Ruthruff, Defer, & Ibrahime, 2018).

Instead, we assume that short-term task practice leads to the formation of modality-specific short-term associations during response selection (see Proctor & Lu, 1999; Proctor et al., 2000, for a dual-route idea). Supposing that modality compatibility is based on ideomotor backward linkages, the specific compatibility associations within the modality mappings can be acquired through life-long response-effect learning in terms of highly over-learned long-term associations. However, being exposed to the modality-incompatible mappings could create short-term (task-specific) associations in WM (i.e., task sets), which should support cognitive remapping processes during multitasking.

More specifically, Maquestiaux et al. (2018) proposed an account in terms of WM systems to explain the modality-compatibility effect after practice by taking modality-specific subsystems, such as the visuospatial sketchpad and the phonological loop, into account (Baddeley & Hitch, 1974). They assume that both stimuli and responses share a common representational system, according to the theory of event coding (see, e.g., Hommel, Müsseler, Aschersleben, & Prinz, 2001), and would be represented within the corresponding WM subsystem. Accordingly, Maquestiaux et al. (2018) explain the modality-compatibility effects as code competition between WM subsystems. In case of modality-compatible tasks, both tasks are represented in distinct WM subsystems, whereas in case of modality-incompatible tasks, WM subsystems have to hold codes from both tasks, thus "executive" processes are needed in order to resolve the competition.

Although the WM approach suggests interesting ideas for the origin of the effect of modality-compatibility, specifically explaining why task automatization is not possible with modality-incompatible tasks as assumed by Maquestiaux et al. (2018), it cannot explain how subsystems could work together without competition. For instance, Fintor et al. (2018) found no observable modality-compatibility effect on switch costs when a modality-incompatible task was combined with a modality-compatible task. More importantly, the present finding that practicing modality-incompatible tasks could reduce modality-compatibility effects might also show that WM subsystems could hold codes for more than one task without competition. More specifically, based on the results of the present study we suggest that short-term pre-exposure could create short-term associations in WM that could override long-term associations by guiding response selection processes to reduce between-task crosstalk.

Based on the idea of Stephan and Koch (2010, 2011, 2016), the modality of the anticipated response effect and the stimulus modality prime each other in modality-compatible tasks as the anticipated effect code and the stimulus code overlap. In contrast, in the modality-incompatible tasks, the modality of the anticipated response effect (i.e., effect code) primes processing of the stimulus modality of the competing task and thus induces between-task crosstalk. During pre-exposure, the modality-incompatible tasks (and their task sets) form short-term associations, so that the system needs to learn how to deal with modality competition of physically present target stimuli and anticipated response effects (e.g., when vocal responses to visual stimuli generate anticipated auditory stimulus codes based on vocal-auditory response effects). As a consequence, the modality of the anticipated effect code might be weighted slightly less in the competition with the stimulus code modality, so that the stimulus code based on the target stimulus "overshadows" or even inhibits the modality feature of the anticipated effect code (Kamin, 1969). Alternatively, or in addition, it is possible that the short-term pre-exposure triggers functional re-mapping processes associating stimulus codes and effect codes with different modalities. This might suppress the adverse influence of the anticipated modality-incompatible response effect. The effect anticipation is functionally a part of response selection, inhibiting one aspect (the modality) of the response effect should generally slow down response selection *within* each task, which we in fact observed as a remaining main effect of modality compatibility after pre-exposure with modality-incompatible tasks, thus strengthening the idea of inhibited modality features of the anticipated effect code and functional remapping. Importantly though, the *between-task* crosstalk in the modality-incompatible tasks is reduced by the down-regulation of the weight of the modality feature of the effect code, resulting in a diminished effect of modality compatibility in task switching. However, a re-mapping of (long-term) associated modalities would also account for a reduced *between-task* crosstalk in the modality-incompatible tasks by suppressing the adverse influence of the anticipated modality-incompatible response effect. Overall, based on our data we cannot yet further distinguish between these alternative accounts and the possibility remains that both the inhibition of modality feature of the anticipated effect code as well as functional re-mapping contribute to the decreased *between-task* crosstalk.

However, it is remarkable that the effect of modality compatibility on switch costs diminishes already after a quite limited short-term pre-exposure (only 320 trials) with modality-incompatible single tasks. Previously, practice effects have only been studied in the context of extensive training in dual tasks (see e.g., Göthe et al., 2016; Hazeltine et al., 2006). While in dual tasking two tasks are processed in parallel, in task switching tasks are processed sequentially. Because task switching is per se more comparable to single-task processing, the influence of single-task pre-exposure might transfer more easily to task switching than to dual-task performance. Please note that in our experiment, only the influence of modality compatibility was affected, while overall switch costs remained with modality compatible and modality incompatible tasks. Due to the methodological differences between the dual-task and task-switching paradigms, it has yet to be demonstrated whether the effect of short-term pre-exposure with single tasks would transfer to dual-task situations or is strictly restricted to task switching. Thus, to further specify and distinguish the underlying mechanisms, further research, desirably with a larger sample size, is needed.

Taken together, the present study provided evidence for a modulation of modality-compatibility effect on switch costs by short-term pre-exposure. The influence of modality compatibility on switch costs was evident in the modality-compatible pre-exposure group, whereas it diminished in the modality-incompatible pre-exposure group. This finding indicates that short-term associations established through pre-exposure to modality-incompatible mappings could override the long-term modality-compatibility effect by inhibiting the anticipation of the modality of the response effect and by functionally remapping between stimulus and effect codes and thus reducing the potential crosstalk in modality-incompatible tasks. The study provides new perspectives not only for modality-compatibility research but also for research investigating practice effects using different modalities in task switching, once more accentuating the complex modulation of the cognitive selection of our motor actions through task context, such as modalities.

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