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Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 44(44)

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Publication Date
2022

Intentional Forgetting of Habits? Combining List-Method Directed Forgetting and Item-Specific Stimulus-Response Priming

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Abstract

Humans are able to intentionally forget declarative memory content as demonstrated in directed-forgetting (DF) experiments. Yet, only few studies assessed whether DF affects associations in procedural memory. We tested how the intention to remember/forget a stimulus affected the formation and/or retrieval of stimulus-response (S-R) associations. To do so, we combined an item-specific priming paradigm with list-method DF. We did not find an impact of the intention to remember/forget on either the retrieval of existing or the formation of new S-R associations: Although participants formed S-R associations (evident in decreasing RTs over stimulis' prime instances), their persisting activation did not impact on RTs in a subsequent item-recognition-test. Potentially, processes contributing to item recognition impeded S-R retrieval. This finding is informative for future studies aiming to assess how intention differentially affects procedural and declarative memory. We formulate experimental design recommendations for future studies assessing the impact of DF on item-specific S-R associations.

Keywords: directed forgetting; habits; stimulus-response associations; procedural memory

Introduction

Many of our everyday actions follow internalized routines. When driving, for instance, we do not put much thought into hitting the brakes when encountering a red light. We appear to be able to exert such (more or less) automatic behavior without controlled processing and deliberate intention. Evidence for the automatic retrieval of actions upon a certain event comes from studies investigating stimulus–response (S-R) associations (e.g., Henson et al., 2014, for a review). S-R associations are formed when stimuli (e.g., red light) and responses (e.g., hitting the brake) repeatedly co-occur and thus bind together – a notion supported by (item-specific) repetition priming effects (see e.g., Henson et al., 2014; Logan, 1988, 1990). In corresponding studies, participants' responses are faster for stimuli that consistently require the same response as opposed to a response different from the previously-executed one. Whereas the automatic retrieval of S-R associations can be beneficial (e.g., when hitting the brakes upon a red light; see e.g., Moors & De Houwer, 2006, for theories of automaticity), there are numerous situations in which people try to *overcome* such existing mental shortcuts (e.g., to break the old habit of snacking while watching TV). The goal of the present research is to investigate whether people can intentionally forget learned S-R associations.

Intentional Forgetting Humans are able to intentionally forget previously-learned information as evident in directed-forgetting (DF) experiments (e.g., E. L. Bjork et al., 1998; R. A. Bjork, 1970; MacLeod, 1998). In the list-method of DF (for an overview see MacLeod, 1998; Sahakyan et al., 2013), participants sequentially learn two lists of items. After learning the first list (referred to as L1), participants are either instructed to forget it or to continue remembering L1 before learning a second list (L2). In a subsequent memory test for both lists (conducted on all items irrespective of the forget/remember instruction), two effects are commonly observed: As illustrated in Figure 1, participants in the forget condition recall fewer L1 items (referred to as L1 forgetting) and more L2 items (L2 enhancement) as compared to the remember condition.

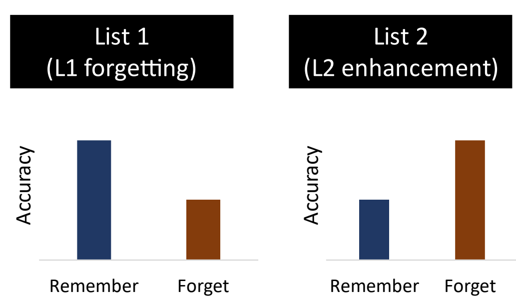

Figure 1: Typical result pattern (see e.g,, Pastötter et al., 2017) for the list-method of directed-forgetting.

Intentional Forgetting of S-R Associations

Whereas many studies have investigated DF of explicitly-learned, declarative information such as lists of words (see MacLeod, 1998, for an overview), few studies demonstrated that DF affects motor representations (Tempel & Frings, 2016) or incidentally-learned information (e.g., Hockley et al., 2016; Jou, 2010). Yet, such types of information form the very basis of habits – which, in everyday life, we often try to intentionally overcome.

So far only a single study has provided initial evidence that incidentally-learned habits (in terms of S-R associations) may be reduced by means of DF (Dreisbach & Bäuml, 2014). The authors found significant S-R repetition priming effects in a testing phase after several S-R pairings in the remember condition. S-R repetition priming effects were, however, absent (Experiment 1) or reduced (Experiment 2) in the forget condition. They argued that participants are generally able to reduce the accessibility or prevent the retrieval of inappropriate habits via a form of retroactive control.

Importantly, in Dreisbach and Bäuml's (2014) study, there are several methodological aspects to consider when further investigating the intentional forgetting of S-R associations. First, participants in the remember group were told to remember what they just did (i.e., performing the same classification task for a small set of items ten times). Hence, their instructions likely led participants to form the intention to recall the respective S-R mappings, rather than just the corresponding items, later on. No such intention was formed for the forget group which was not given any memory instruction or prompt for a later memory test. Thus, the design of remember/forget instructions potentially explains the performance differences between the two groups. Second, at test, when participants again responded to items after the initial S-R learning phase, they responded ten times to each item which resulted in substantial additional S-R learning across test instances (Dreisbach & Bäuml, 2014; see supplementary material). It is unclear whether an effect of memory instruction can be observed already for the first test trial per item (see their supplementary analyses as a function of binned test instances). Third, S-R mappings remained fixed per block and did not switch on a trial-by-trial basis. That is, participants might have formed category-response associations (e.g., Longman et al., 2018) in addition to S-R associations which confounds the assessment of what was potentially forgotten. Finally, in their Experiment 1, reaction times (RTs) in the remember group were substantially larger than in the forget group – even when considering items for which responses repeated between learning and test. This is surprising, because *if* participants truly encoded S-R associations that were later not sufficiently accessible in the forget group, one would expect the opposite pattern of results: RTs should be faster for repetition trials in the remember (because the learned S-R associations facilitate performance at test) than in the forget group. These aspects suggest that further assessments are essential to determine whether S-R associations can intentionally be forgotten.

Here, we aimed to replicate the effect of intention on the encoding and/or retrieval of S-R associations while considering the described methodological challenges. In sum, the aim of the present study was to replicate and extend findings regarding the intentional forgetting of S-R associations (1) using a larger stimulus set, (2) using a single probe instance to avoid additional implicit learning during the test phase, and (3) ensuring that participants encoded solely item-specific S-R associations and not also category-response associations (i.e., switching/repeating S-R mappings on a trial-by-trial basis). At the same time, we equated the intention to memorize items between the forget and the remember group and selectively instructed the memorization of items (as compared to entire S-R episodes). Thereby, we aimed to gain a deeper understanding of the mechanisms underlying the DF effect on S-R associations.

The Present Study

The goal of the present study was to test whether S-R associations can be intentionally forgotten. To do so, we used a new experimental DF design to investigate the effect of DF on S-R retrieval.

The present experiment had three major phases: A learning phase, a distraction phase, and a test phase. During the learning phase, participants' task was to categorize images of objects in two lists (L1 and L2) as containing a mechanism or not (item-specific priming task adapted from Hsu & Waszak, 2012; Moutsopoulou et al., 2015; Pfeuffer et al., 2017) by pressing a left/right key. A cue preceding each item indicated whether a left or right response was required for a mechanic versus non-mechanic classification, respectively. As a secondary task, we instructed participants to remember the images for a later memory test. Like in prior list-method DF studies, between L1 and L2, half of the participants were instructed to either continue remembering the images of L1 (remember condition) or to forget them (forget condition). Following a subsequent distractor task, in the test phase, participants were presented with all images from the learning phase (L1 and L2 regardless of the memory instruction) as well as new images. Participants were instructed to recognize the images they previously categorized/learned (L1 and L2) and to classify them as old (i.e., previously-seen) as compared to newly-presented images. They did so by pressing a left/right key as indicated by a task-cue presented prior to the images. Importantly, for half of the old images (previously-presented in the learning phase), the S-R mappings at test were the same as they had been in the learning phase (item-specific *response repetitions*; i.e., the same response was required). For the other half of the old images, the S-R mappings at test were reversed (item-specific *response switches*, e.g., a stimulus mapped to a left response in the learning phase now required a right response). We used the difference in RTs and error rates in the test phase between trials that required an item-specific response switch versus an item-specific response repetition (*S-R effects*) to assess S-R associations.

Hypotheses In a typical item memory test for L1 and L2 in the list-method of DF, participants in the forget condition recall fewer L1 items (L1 forgetting) and more L2 items (L2 enhancement) as compared to the remember condition. Because L1 forgetting costs and L2 enhancement can be observed independent from one another (Pastötter & Bäuml, 2010; Sahakyan & Delaney, 2003), both retrieval and encoding processes are assumed to contribute to list-method DF effects (for an overview see Pastötter et al., 2017). Applying these observations to the context of S-R associations we expected the following observations.

List 1 forgetting for S-R associations. The context change hypothesis (one of the most prominent theories on list-method DF introduced by Sahakyan & Kelley, 2002) postulates that between the study of L1 and L2, upon the forget instruction, participants deliberately change their mental context to intentionally forget L1 items. Thereby, new context cues are associated with the subsequent L2 information resulting in a larger than normal context change between L1 and L2 (Sahakyan & Kelley, 2002). At test, the current context mismatches the L1 context impeding the recall of L1 items in the forget group. If DF influences the retrieval of S-R associations similarly, L1 S-R associations may be harder to retrieve in the forget as compared to the remember group. As a result, item-specific S-R effects for L1 items at test should be smaller for the forget as compared to the remember group.

List 2 enhancement for S-R association. The reset of encoding hypothesis (see Pastötter et al., 2017) assumes that encoding of early L2 items is enhanced via the reset of encoding processes (e.g., due to reduced working memory load and reduced inattention). This is evident in a stronger L2 primacy effect in the forget as compared to the remember group when testing participants‘ memory for L2 words (Pastötter & Bäuml, 2010). Under the assumption that the encoding of items and S-R associations (at least partly) depend on similar processes and resources, the reset of encoding processes for items (i.e., corresponding to reduced working memory load) may not only enhance the encoding of subsequent items but also of subsequently associated information, here, S-R associations. If DF enhances the subsequent learning of novel S-R associations, then, the S-R effects for L2 items at test should be greater in the forget as compared to the remember condition (L2 enhancement).

Method

The experimental set-up, hypotheses, and data analysis plan were pre-registered under (https://osf.io/wuzvx).

Participants

In total, 76 participants took part in the experiment for course credit or monetary compensation (6 EUR). Half of the participants were randomly assigned to the remember condition and the other half to the forget condition. All participants gave written informed consent prior to the start of the experiment. Dreisbach and Bäuml (2014) observed a partial eta squared of $\eta p2 = .14$ and $\eta p2 = .06$ for the critical interaction between instruction and compatibility (parallel of item-specific repetition vs. switch) in their RT analyses. Power analyses using G*Power (Faul et al., 2007) on the mean $\eta p2 = .10$ suggested a sample size of $N = 76$ to detect a significant effect (with $\alpha = .05$ and $1\text{-}\beta = .8$). From the initial sample, we excluded five participants that committed errors or response omissions in more than 30% of the trials in the learning or test phase. These participants were replaced by new ones. Only one participant was suspicious about the purpose of the restart of the experiment and was excluded, resulting in a sample size of $n = 75$ participants.

Trial Structure and Procedure

Experimental set-up The experiment took place in a sound-attenuated laboratory room. Participants sat approximately 60 cm from a 24” (1920x1080) LCD monitor. Participants’ index fingers rested on two external keys placed in front of them to the left and right (key distance 13.5 cm).

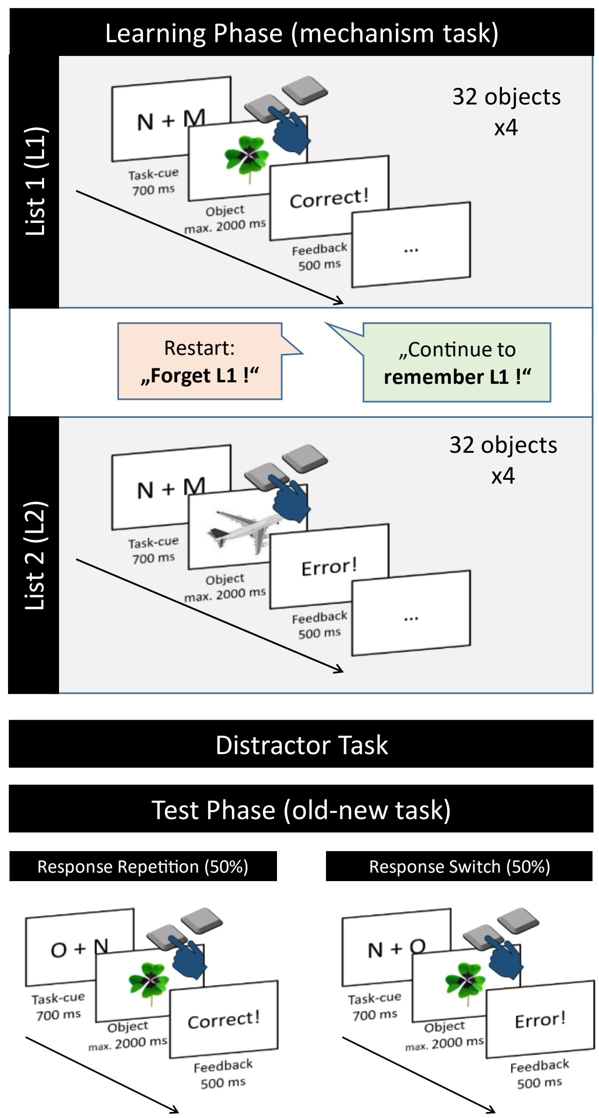

Figure 2: Trial Structure and Procedure.

Material The experiment was conducted in German. Images of everyday objects served as stimuli and were taken from previous studies conducted by Pfeuffer et al. (2017; stimulus set originally from Brady et al., 2008; Moutsopoulou et al., 2015). Participants classified images according to whether they contained a mechanism or not (e.g., wheels, levers, electronic parts; "mechanisch", Engl. mechanic vs. "nicht-mechanisch", Engl. non-mechanic) using a left or right external response key. From the original set of 512 images used by Pfeuffer et al., we selected a subset of 128 images (64 mechanic / non-mechanic objects; 256 x 256 pixels, about 8° visual angle). Item selection was based on the data of two previous studies conducted by Pfeuffer et al. (see Pfeuffer et al., 2017, 2020): The easiest to categorize images in these studies (least amount of categorization errors across participants) were selected. Furthermore, two items were excluded as they were easy to categorize but similar to one another. Three item lists were randomly created for each participant: L1 and L2 (learning phase), contained 32 different images with 16 mechanic and 16 non-mechanic images each. The test list contained all 64 images of the learning phase and 64 new images.

Procedure The experiment consisted of three phases (see Figure 2): a learning, a distractor, and a test phase. Instructions were given on the screen and summarized by an experimenter. In an initial practice block (eight new images), participants were familiarized with the classification task.

Learning phase. The learning phase consisted of two lists (L1+L2). Participants were instructed to categorize items according to their mechanism category (mechanic vs. non-mechanic) by pressing a left or right key. At the same time, they were told to remember the images of the objects for a later memory test. The trial started with the presentation of the task-cue (700ms) indicating whether a left or right response was required for a mechanic/non-mechanic classification for the subsequent image. For example, the task cue "M + N" indicated that participants needed to press the left key for the classification "mechanic" and the right key for the classification "non-mechanic". Next, the object image was presented. Participants had to classify the object as fast and accurately as possible (response limit 2000 ms) by pressing the key (left vs. right) that spatially corresponded to the correct object classification. A feedback screen followed, informing participants about their response´s correctness (500ms; "richtig!"/ Eng: "correct!" for correct responses; "Fehler!"/ Eng.: "error!" for incorrect responses; "zu langsam!"/ Eng: "too slow!" for response omissions).

Each object of a list was presented four times (four prime instances) in its corresponding list (in four separate blocks of the 32 images) to build strong S-R associations. Here, one prime instance refers to one pairing of a stimulus with a specific response. Importantly, the S-R mapping for an object was the same for all learning instances (e.g., a right key press was required for all learning instances).

Forget condition. After the items of L1 were classified and learned like this, participants in the forget condition were instructed to forget the so-far-presented items following the typical list-method DF procedure (e.g., see Sahakyan et al., 2013). Specifically, after L1, a computer screen gave an arbitrary overview of participants' performance and the presumed current condition of the experiment. The participants were asked to go to the experimenter in order to continue the experiment with the next condition. The experimenter then stepped in, read over the summary, and apologized for having accidentally started the experiment with the incorrect condition. Thereupon, the experimenter left the room pretending to ask the leading researcher what to do next. The experimenter re-entered the room after roughly 60s and informed the participants that they could restart the experiment in the correct condition. Participants were kindly asked to start over again with the correct condition. They were casually told to try to forget what they had just done (i.e., to forget the images they had memorized, but no instruction was given regarding the S-R mappings). The experiment was restarted, and the participants were again instructed to forget everything they have previously learned. The instruction emphasized the importance of trying to forget the previously-presented images and only to concentrate on the subsequently to-be-categorized images.

Remember condition. After the objects of L1 were classified and learned, a screen was presented providing participants with the same arbitrary experimental overview as in the forget condition. Again, the experimenter entered the room to continue the experiment. In contrast to the forget condition, however, participants were simply told that they had finished the first part of the learning phase and were going to continue with the second part. Participants were casually told to continue remembering the L1 images.

Distractor phase. Following L2, to purge working memory, a 3-min distractor task (a computerized version of the Corsi block-tapping Task; CORSI; forward span; Corsi, 1973) was conducted.

Test phase. Next, in the test phase (128 trials over four blocks) participants were instructed to recognize the images they previously categorized/studied (L1 and L2). Participants in the forget condition were explicitly informed that the simulated experiment restart was part of the experiment and that they should now try to remember the images from both before and after the simulated experiment restart. Instead of categorizing the objects as mechanic and non-mechanic, participants now identified whether an image had been presented in the learning phase (category: "old" - O) or not (category: "new" - N). They did so by a pressing left/right key as indicated by a task-cue presented prior to the images that could switch on a trial-by-trial basis. Importantly, half of the old items from the learning phase had the same (*item-specific S-R repetition;* e.g., left response was required to classify an object as "mechanic" in the learning phase and to classify it as "old" in the test phase) and the other half the opposite S-R mappings as in the learning phase (*item-specific S-R switch*).

Using post-experimental questions, we checked whether participants had any suspicion about the restart of the experiment. Participants were properly debriefed about the simulated experiment restart and its reason. Last, they were asked not to tell friends and colleagues about the simulated experiment restart.

Data Analysis

We used a mixed models approach (for an overview see Baayen et al., 2008; Judd et al., 2012). Log-transformed RTs of the test phase were analyzed using linear mixed models (LMMs) and we analyzed the correctness of responses using generalized mixed models (GLMMs) with a binomial link function. The LMM on participants' RTs were fitted using maximum likelihood estimation for model selection and restricted maximum likelihood (REML) estimation for slope estimates. *p*-values for effects were obtained using the Kenward-Roger (Kenward & Roger, 1997) approximation for denominator degrees of freedom. The models consisted of the fixed factors *response* (repetition vs. switch, within) and *instruction* (remember vs. forget, between) as well as the corresponding interaction. We implemented the maximal random-effects structure justified by the design as suggested by Barr et al. (2013). Because this model did not converge, we reduced the random effects structure step-by-step (beginning with by-image random slopes) until the model converged (pre-registered procedure). The final models that converged had random intercepts for participants and images (model for L1 + L2) as well as a by-participant random slope for response (model for L2 only).

Results

We discarded trials with response omissions in the learning or test phase (n_{trials} = 46, 0.2% of the data) from all analyses. For the trials in the test phase, only the trials with correct responses in all four corresponding learning instances of the learning phase were used (excluded n = 6545, 22.9%). For the analyses of RTs, we excluded trials with incorrect responses and RTs above/below 3SD of the individual cell means (n = 236, 1.1%). None of the reported results changed when including incorrect responses in the RT analyses. Mean RTs are plotted in Figure 3. Table 1 and Table 2 show the results and model statistics of the RT and the error model, respectively. In short, for the trials of the test phase, none of the fixed effects reached statistical significance.

Table 1: Model Results for the Test-Trials RTs (L1+L2).

Predictors	Est.	SE	*df*	*t*	*p*
List 1					
(Intercept)	6.60	0.23	73.8	270.1	<.001
Response	-0.00	0.01	1330	-0.2	.818
Instruction	-0.02	0.02	73.0	-0.6	.541
Resp. x Instr.	0.00	0.01	1332	0.0	.971
List 2					
(Intercept)	6.57	0.23	77.3	287.0	<.001
Response	-0.01	0.01	73.3	-0.9	.390
Instruction	-0.02	0.02	73.0	-1.0	.316
Resp. x Instr.	0.00	0.01	73.0	-0.1	.948

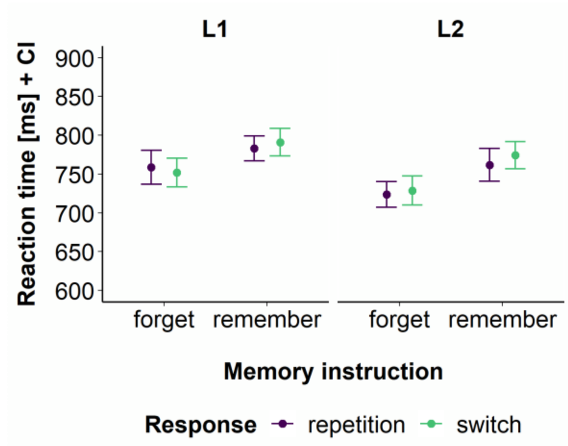

Figure 3: Mean test-trials RTs for List 1 (L1), List 2 (L2). Error bars: within-subject 95% confidence intervals.

Table 2: Model Results for Test-Trial Errors (L1+L2).

Predictors	Est.	SE	*z*	*p*
List 1				
(Intercept)	-1.80	0.10	-17.4	<.001
Response	0.07	0.08	0.9	.370
Instruction	-0.04	0.09	-0.4	.672
Response x Instruction	0.05	0.07	0.7	.491
List 2				
(Intercept)	-2.21	0.12	-18.0	<.001
Response	-0.03	0.08	-0.4	.704
Instruction	-0.03	0.10	-0.3	.791
Response x Instruction	0.03	0.08	0.3	.754

To test whether participants encoded S-R associations at all during the learning phase, we analyzed participants' RTs across the four prime instances in L1 and L2. As illustrated in Figure 4, participants RTs substantially dropped over the four learning instances in both L1 (LMM, t = -16.2, p <.001) and L2 (t = -21.1, p <.001) indicating S-R learning. Although L2 responses descriptively revealed a pattern of faster responses in the forget as compared to remember group for the first L2 prime instances, we lack statistical evidence for this difference in our LMM (t = 1.5, p =.135).

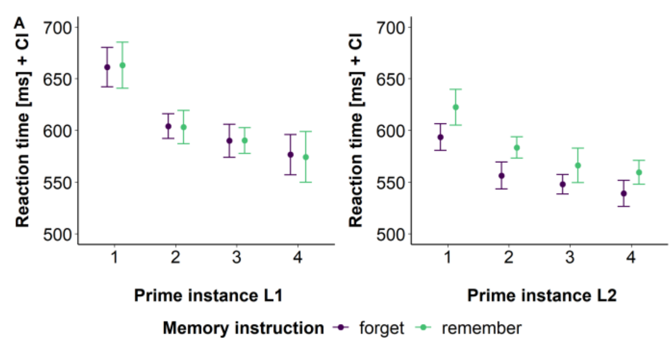

Figure 4: Mean reaction times (RTs) in L1 and L2. Error bars represent the within-subject 95% confidence intervals.

Discussion

The present study tested whether S-R associations can be intentionally forgotten by designing a novel item-specific priming version of list-method DF. Whereas prior studies found evidence for intentional forgetting of item information (e.g., E. L. Bjork et al., 1998; MacLeod, 1998), the present study found no evidence for the intentional forgetting of S-R associations. Surprisingly, although participants evidently encoded S-R associations during the learning phase, these S-R associations did not impact performance in a subsequent item recognition test in general.

Initially, we expected that DF would impact both the retrieval of already existing L1 S-R associations as well as the encoding of novel L2 S-R associations. For instance, for L2 items, the reset of encoding hypothesis (for an overview see Pastötter et al., 2017) assumes that, upon encountering the forget instruction, the encoding process is reset and encoding of early L2 items is enhanced (e.g., Pastötter & Bäuml, 2010). We assumed that the forget instruction would reset encoding processes not only for L2 items, but also for S-R associations. Hence, we expected to find stronger item-specific S-R effects for L2 items in the forget as compared to remember condition. This was not the case. Moreover, for L1 items, the context change hypothesis (Sahakyan & Kelley, 2002) assumes that participants in the forget group deliberately change their mental context to intentionally forget L1. This leads to reduced accessibility of (and hence worse memory for) L1 items in the forget group (L1 forgetting). Contrary to this well-established result for item memory, we found no impact of DF on item-specific S-R effects of L1 items at test. That is, we found no indication that forget instructions affected the retrieval of S-R associations formed in L1.

At first glance, our finding – that DF did not impact the retrieval of L1 S-R associations – seems to contradict Dreisbach and Bäuml's (2014) study that also investigated DF of S-R associations but found reduced or no S-R effects for L1 items in the forget as compared to remember group (in line with the context change account). However, there are multiple experimental design factors explaining the contrasting results – as detailed in the Introduction. Most essentially, we generally did not observe S-R effects for the RTs and error rates in the recognition test. Therefore, of course, we could not find a modulation of S-R effects in the presents study. It is, however, surprising that, although participants clearly encoded S-R associations during the learning phase (see Figure 4), these associations did not affect RTs in the recognition test. We consider two possible explanations for this finding.

First, we additionally asked participants to remember the list images in the learning phase while categorizing the objects. Contrary to prior item-specific priming studies (e.g., Henson et al., 2014, for a review), we did not observe significant item-specific S-R repetition priming effects even in the remember group. This suggests that, potentially, the instruction to also remember the object images for a later memory test may have interfered with the encoding of S-R associations in the learning phase (e.g., due to dual-task load).

On the one hand, the absence of any item-specific S-R effects at test even in the remember group seems to support this conclusion. Likewise, processes contributing to item recognition in the memory test could have overshadowed any potential S-R effects. For instance, according to signal detection theory, item recognition decisions are based on a familiarity signal produced from the presented item in relation to an internal decision criterion (Wickens, 2001). Such recognition-related processes may have interfered with the retrieval of S-R associations or may have generally led to higher RTs obstructing the commonly small item-specific S-R repetition priming effects.

On the other hand, participants' RTs became significantly faster across the four prime instances of both L1 and L2 (see Figure 4). This observation clearly indicates S-R learning during the learning phase (if not only perceptual learning contributes to this finding). Hence, we consider it unlikely that the additional memory instruction prevented participants from encoding S-R associations completely.

Our results allow us to formulate experimental design recommendations for future studies assessing the impact of list-method DF on item-specific S-R associations: First, our findings show that participants can encode S-R associations while simultaneously memorizing the items they process (because participants evidently encoded S-R associations in the learning phase). Hence, future work can indeed combine a memory task with a repetition priming paradigm to assess the interplay of declarative and procedural memory. Second, if it is not the encoding of S-R associations that is prevented by the additional memory instruction (and item recognition processes do not overshadow retrieval of S-R associations at test), our results demonstrate that processes contributing to item recognition must have interfered with the retrieval of S-R associations. Future research should therefore take special care not to intermix both types of measures. That is, measures intending to assess item-specific S-R repetition priming effects need to be separate from measures intending to assess item memory.

Conclusion. The current study shows that although participants can encode S-R associations while simultaneously intending to memorize the items they process, the resulting item-specific S-R repetition priming effects cannot be measured when the retrieval of S-R associations and item memory compete. Therefore, future researchers need to separate measures intended to assess S-R effects from measures intended to assess item memory.

Importantly, this new item-specific priming design for DF experiments lays the groundwork for future studies that aim to investigate how intention differentially affects procedural (S-R associations) and declarative (e.g., items) memory. This is important because only few studies have at all assessed DF for procedural representations (Dreisbach & Bäuml, 2014, Tempel & Frings, 2016). Future research is needed to further elucidate the mechanisms underlying DF regarding information represented in declarative versus procedural format.

Acknowledgments

This research was supported by the German Research Foundation, DFG (Grant RA1934/5-1 and RA1934/8-1) within the SPP 1921 "Intentional Forgetting".

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