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How motor practice shapes memory: retrieval but not extra study can cause forgetting

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We investigated the retrieval specificity of retrieval-induced forgetting (RIF) of motor sequences. In two experiments, participants learned sequential finger movements, each consisting of the movement of two fingers of either the left or the right hand. In the learning phase, these motor sequences were graphically presented and were to be learned as responses to simultaneously presented letter stimuli. Subsequently, participants selectively practiced half the items of one hand. A final recall test then assessed memory for all initially learned items. We contrasted different kinds of selective practice with each other. Whereas retrieval practice required retrieving motor sequences in response to letter stimuli from the learning phase, extra study was an extension of the learning phase, that is, participants performed motor sequences in response to the same animation graphic display as in the learning phase again accompanied by the letter stimulus. All practice conditions strengthened the practiced items, but only retrieval practice resulted in RIF. Thus, the strengthening of items through practice did not suffice to induce forgetting of related motor sequences. Retrieval was a necessary component for practice to shape memory for body movements by impairing the subsequent recall of motor sequences that were related to the practiced motor sequences.

Keywords: Retrieval-induced-forgetting; Body movement; Recall.

Doing sports or playing a musical instrument requires practice—the way to mastery involves thorough exercises. Repeating the same body movements over and over again aims at the acquirement of fluent motor sequences that can quickly be retrieved from memory. There are various ways of practicing body movements, of course. Exercises may focus on exact repetition of movement patterns or on the generalisation and transfer of skills. Feedback may be given permanently or sparsely, immediately or after a delay. The investigation of such variables suggests that comparing the efficiency of different training techniques depends on the outcome of interest with some benefiting primarily the speed of acquisition whereas others rather benefit retention (cf. Schmidt & Bjork, 1992). Here, we focus on comparing the effects of practice with and without retrieval.

Practice seems to be especially effective if it involves memory retrieval. The *testing effect* is the phenomenon that retrieval improves memory for the retrieved information more than mere repetition (Allen, Mahler & Estes, 1969; Bjork, 1975; Roediger & Karpicke, 2006). Whereas most studies concerned with the benefits of retrieval relied on verbal material, recent studies also explicitly focused on testing effects in motor action. For example, Boutin, Panzer, and Blandin (2013) demonstrated that testing improved the generalisation of a dynamic arm movement skill (see also, Boutin, Panzer, Salesse, & Blandin, 2012). Kromann, Jensen, and Ringsted (2009) showed

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that testing at the end of a resuscitation course for medical students enhanced the retention of resuscitation skills.

However, practice has side effects. Whereas practice is beneficial for the memory of the practiced material, it can impair related memories. Retrieval-induced forgetting (RIF) is the phenomenon that selectively retrieving information from a set of information stored in memory can cause the forgetting of non-retrieved information from this set. RIF is analysed in the retrieval-practice paradigm (Anderson, Bjork, & Bjork, 1994) that consists of three main phases. In the learning phase, participants study several sets of items in combination with a shared (category-)cue that defines the specific set of items (e.g., flower—rose, flower—tulip, fruit—banana, fruit—cherry). In the subsequent retrieval-practice phase, participants are cued to recall half of the studied items from half of the sets (e.g., flower—ro__). In the test phase then, recall performance for all items is tested. The recall of practiced items (Rp+ items; e.g., rose) and unpracticed items from practiced sets (Rp− items; e.g., tulip) is compared to the recall of unpracticed items from unpracticed sets (Nrp items; e.g., banana, cherry). Rp+ items typically profit from retrieval practice and are better recalled than Nrp items. RIF manifests itself in significantly worse recall of Rp− items as compared to Nrp items.

Recently, the retrieval-practice paradigm has been adapted for investigating motor memory (Tempel & Frings, 2013). Participants first learned 12 sequential finger movements (SFM), each consisting of 2 consecutive key presses in response to a letter stimulus. Six items involved two fingers of the left hand, six involved two fingers of the right hand (e.g., left ring finger, left index finger). After retrieval practice on three items of one hand, a final recall test assessed memory for all items. Rp+ and Rp− items pertained to one hand, and Nrp items pertained to the other hand. Rp− items were tested before Rp+ items in order to preclude any output interference by Rp+ items (cf. Anderson et al., 1994; Roediger & Schmidt, 1980). Rp− items were accordingly compared to the first three Nrp items tested (Nrp1), whereas Rp+ items were compared to the last three Nrp items tested (Nrp2). Significantly fewer Rp− than Nrp1 items were recalled. Also, response times (RTs) to Rp− items were significantly longer than RTs to Nrp1 items (see also Reppa, Worth, Greville, & Saunders, 2013; Tempel & Frings, 2014a). In addition, we found that RIF of motor sequences also occurs in indirect memory tests that required the execution of movements overlapping with the learned items only in the respective motor programmes (Tempel & Frings, 2014b, 2015), suggesting that the processes underlying RIF affected motor programmes. In those indirect tests, participants had to execute the same motor sequences as in the learning phase while entering novel stimuli via the keyboard. The performance in this task overlapped with the preceding tasks of learning and retrieval-practice trials solely regarding the to-be-executed movements. However, it is not clear so far whether these processes depended on memory retrieval or if other kinds of motor practice not involving retrieval equally would entail forgetting. The previous experiments were not able to demonstrate whether retrieval attempts were necessary for inducing forgetting because the effects of retrieval practice were never compared with the effects of retrieval-free practice. Perhaps, the term RIF was in reality inappropriate since Rp− items were impaired because the strengthened Rp+ items interfered at test blocking access to Rp− items. Therefore, we here scrutinised if selective motor practice also entails similar forgetting effects when it does not involve memory retrieval.

The contribution of retrieval to practicing body movements only seldom has been scrutinised, although it has been suggested that retrieval is a crucial element in many training techniques (cf. Schmidt & Bjork, 1992). Athletes or musicians do not solely rely on restudying but include the retrieval of motor sequences as a natural component in their exercises. Therefore, it is important to know whether retrieval practice entails specific consequences that do not follow on other retrieval-free ways of practice. With regard to verbal material, it has been shown that not every kind of practice induces forgetting of related information. RIF has been shown to be retrieval-specific in several studies comparing selective retrieval practice with selective extra study (Bäuml, 2002; Ciranni & Shimamura, 1999; Staudigl, Hanslmayr, & Bäuml, 2010; for a meta-analysis see: Murayama, Miyatsu, Buchli, & Storm, 2014). Only retrieval practice impaired memory for related items. In contrast, extra study instead of retrieval practice did not induce forgetting of related items. This finding suggests that RIF is not merely a product of interference at test arising from the strengthened Rp+ items. However, properties of phenomena in verbal memory cannot be readily transferred to motor memory. Since different brain systems are likely involved in encoding and processing verbal versus motor content (e.g., Krakauer & Shadmehr, 2006), processes of interference and inhibition may operate differently as well. In general, current memory research unnecessarily neglects motor action. A notable exception is work by Anderson (2003) who explicitly linked inhibition in memory with behavioural inhibition in motor action, both achieving a kind of response override (see also Anderson & Weaver, 2009). Yet, empirical investigations of retrieval dynamics in motor memory are scarce. Hence, more studies are needed examining in which regard motor memory operates in similar or disparate ways.

Retrieval specificity is one of the key predictions of the inhibitory account of RIF (Anderson, 2003; Anderson et al., 1994; Anderson & Spellman, 1995; Storm & Levy, 2012; Wimber, Alink, Charest, Kriegeskorte, & Anderson, 2015). This theory assumes that during retrieval practice of one item the other items of this set interfere in a competition for conscious recollection. The retrieval attempt is necessary for this competition to arise. In order to resolve this interference, the Rp+ items are strengthened while simultaneously the Rp− items are inhibited. Translated to motor sequences, the inhibitory account implies that inhibition resolves interference arising between motor programmes because RIF has been shown to occur in indirect memory tests overlapping with motor sequences acquired in the learning phase only in the to-be-executed movements (Tempel & Frings, 2014b, 2015). In contrast, extra study might not affect motor programmes because no interference between motor programmes may arise during extra study.

We investigated if selective practice of a subset of body movements stored in memory also has to involve retrieval for inducing forgetting of non-practiced movements of the same set. Thus, we tested whether retrieval dynamics that have been proven to work in declarative memory affect motor memory in the same way. Perhaps, motor practice without retrieval suffices to impair later recall of related non-practiced movements. Selectively executing some movements repeatedly might strengthen these movements in a way that they block access to related movements. To this end, we compared practice without retrieval versus retrieval practice and therefore were able to analyse for the first time whether retrieval at practice is a precondition for RIF in motor memory.

EXPERIMENT 1

In Experiment 1, we contrasted two conditions. In both conditions, participants first learned 12 SFM as responses to letters. During a learning trial a letter appeared at the centre of the computer screen together with an animation graphic display of the corresponding two-finger-movement. Immediately after this animation, participants executed the just displayed SFM by pressing corresponding keys. Six items were executed with fingers of the left and six with fingers of the right hand. One experimental condition then involved selective retrieval practice of items. Participants had to retrieve three items of one hand in response to their letter stimuli. A letter appeared on the screen and the participant entered the corresponding item while his or her fingers rested on the same keys as in the learning phase. We expected to replicate an RIF effect (Tempel & Frings, 2013). The selective retrieval practice of three items of one hand (Rp+) should induce forgetting of the three non-retrieved items of this hand (Rp−) as compared to items of the other hand (Nrp). The other condition involved selective extra study. Participants selectively practiced the same items as in the first condition, but, instead of retrieval practice, they received additional learning trials for three items of one hand by means of the same format as in the learning phase, that is, they performed the SFM in response to the same animation graphic display as before accompanied by the corresponding letter. The participants' task in the extra study phase, hence, was identical to the preceding learning trials. They entered the displayed SFM and were instructed to memorise it in response to the simultaneously presented letter stimulus. Thus, participants in both conditions selectively practiced a subset of items, but the kind of practice differed by only involving retrieval in one condition. The final test phase was identical in both conditions. We expected no RIF to occur in the extra study condition. In contrast, Rp+ enhancement should occur in both conditions.

Method

Participants

Sixty-four psychology students at the University of Trier (53 women, mean age = 21.6, SD = 4.9) participated in the experiment. They received course credit for their participation.

Design

The study had a 2 (retrieval practice, extra study) × 4 (item type: Rp+, Rp–, Nrp1, Nrp2) mixed design with repeated measures on the last factor.

Material

The experiment was conducted using Dell Optiplex 755 PCs with Eizo FlexScan S1901 monitors and standard German QWERTZ keyboards. The software PXLab (Irtel, 2007) served for running the experiment. The items consisted of 12 two-finger movements. Six two-finger movements consisted of fingers of the left, the other six of fingers of the right hand. Participants learned these movements as responses to letters. The letters *a* to *f* were the stimuli for the left-hand movements, the letters *u* to *z* for the right-hand movements (see Appendix A). During the learning phase a letter appeared at the centre of the computer screen together with an animation of the corresponding two-finger-movement (cf. Figure 1). The fingers of the left hand were placed on the keys *Q*, *W*, *E*, and *R*. The fingers of the right hand were placed on the keys *U*, *I*, *O*, and *P*. Below the letter a display of the two hands demonstrated which fingers should be moved by showing two consecutively flashing fingers (first finger was coloured yellow, second finger was coloured blue, 200 ms per flash). After the display of the two hands disappeared participants could perform the movement. If the performed sequence was incorrect a feedback appeared, displaying: *Fehler!* (English: *Error!*).

Procedure

The experiment consisted of four phases (learning, selective practice, distractor task, final recall). Instructions were given on the screen and summarised by an experimenter. After having read the instructions for the learning phase the participant clicked an on-screen button in order to start with the learning phase. Participants had 10 seconds to place their fingers with exception of the thumbs on eight keys (*Q*, *W*, *E*, *R*, *U*, *I*, *O*, and *P*) marked by labels hiding the inscription. Then, the learning of the 12 items began. Participants had to consecutively press two keys in response to a displayed letter accompanied by an animation graphic display showing which digits should be moved (cf. Figure 1, upper section). First, all 12 items appeared once in random order, whereupon an instruction screen informed the participant that the items just presented would appear again several times in the following. Eleven blocks each containing the 12 items in a random order were presented.

The selective practice phase differed between the two experimental conditions. In the retrieval-practice condition, participants had to retrieve three items of one hand. The items were cued by their letter stimuli. A letter appeared on the screen and the participant entered the corresponding item while his or her fingers again rested on the marked keys (cf. Figure 1, middle section). No feedback about the accuracy of the performed two-finger-movement was given. In the extra study condition, participants received additional learning trials for three items of one hand by means of the same format as in the preceding phase, that is, they performed the SFM in response to the same animation graphic display as before accompanied by the corresponding letter. Thus, the participants' task in the extra study phase was identical to the preceding learning trials. They entered the displayed SFM and were instructed to memorise it in response to the simultaneously presented letter stimulus. Whereas instructions in the retrieval-practice condition explained that participants had to retrieve items of either the left or the right hand in response to their letter stimuli, instructions in the extra study condition stated that additional learning trials for items of either the left or right hand would follow. In both conditions, counterbalancing of the practiced items resulted in four practice sets (*abc*, *def*, *uvw*, and *xyz*). These four sets were counterbalanced between participants. The items were practiced five times in both conditions.

As typical for the retrieval-practice paradigm, we increased the retention interval by running a distractor phase. The distractor phase comprised an aesthetic judgement task. Using a mouse the participants disclosed abstract paintings on the computer screen by clicking on-screen buttons, and subsequently rated how appealing these paintings were to them. Sixteen paintings were rated. The mean time taken for this task was 3.2 minutes (SD = 0.5).

The final test phase presented participants with the 12 letter stimuli in the same fashion as during the selective practice phase in the retrieval-practice condition (cf. Figure 1, lower section). The items of one hand were presented in succession,

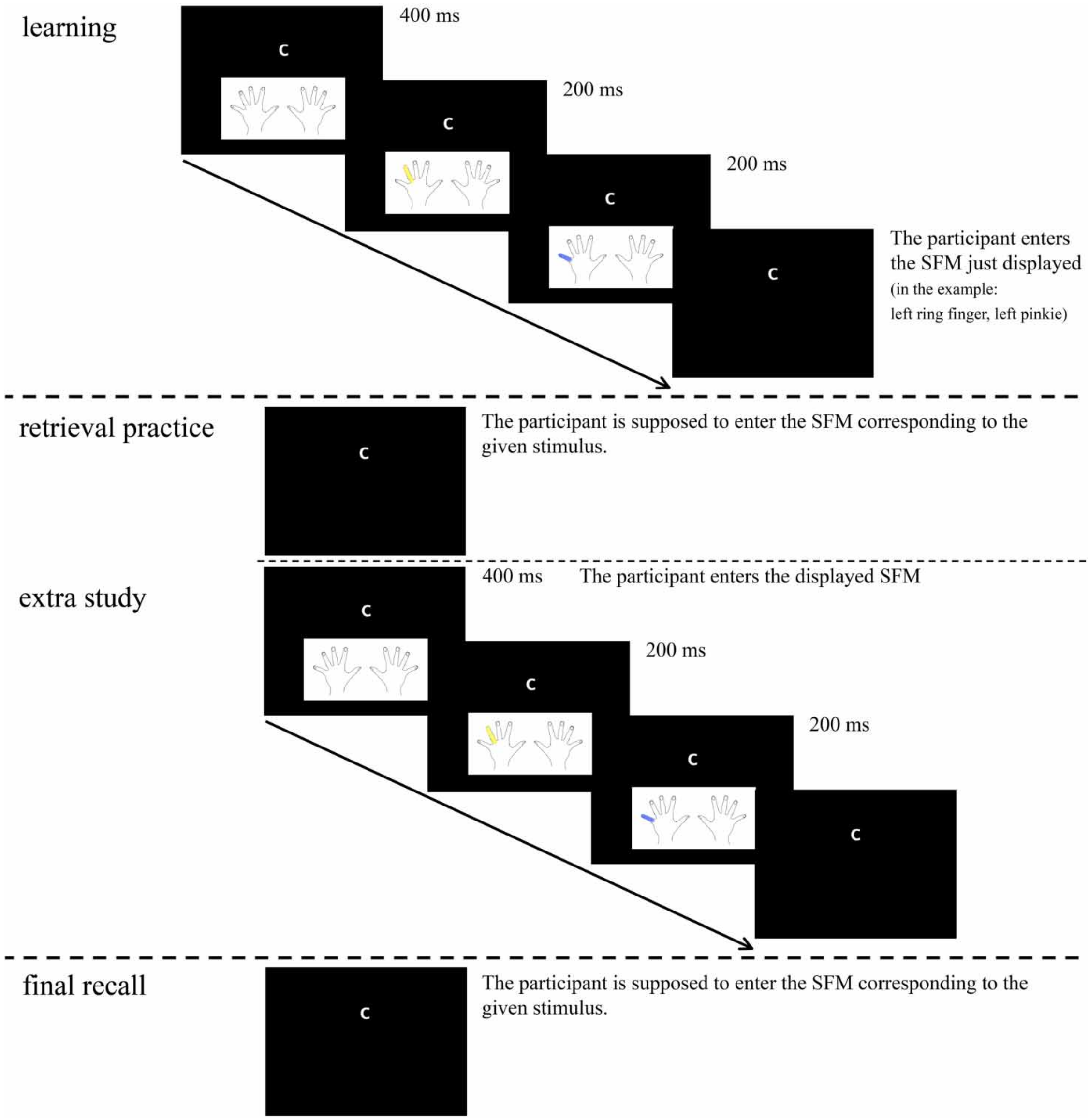

Figure 1. The upper section depicts a trial in the learning phase. It starts with a display of the letter stimulus together with a drawing of the two hands. After 400 ms the first finger illuminates yellow for 200 ms and then the second finger illuminates blue for 200 ms. Subsequently, the hand display disappears and the participant can enter the SFM just illustrated. In the selective retrieval-practice, a stimulus is given and the participant is supposed to perform the corresponding SFM without receiving feedback about his or her response. In contrast, extra study trials required the execution of SFM in response to the same animation as in the learning phase. The lower section depicts a trial in the final recall phase. A stimulus is given and the participant is supposed to perform the corresponding SFM. SFM, sequential finger movement.

that is, the test was blocked by hand. The test either started with the left or the right hand. It was counterbalanced if the test sequence started with the practiced or with the non-practiced hand. Within the items of the practiced hand the Rp− items were tested before the Rp+ items in order to avoid effects of output interference (cf. Anderson et al., 1994). Within the items of the non-practiced hand the items were presented in one of two sequences thereby counterbalancing which items constituted Nrp1 items and Nrp2 items.

Results

Mean retrieval success in the selective practice phase of the retrieval-practice condition was

49% (SD = 23%). For analyses of RTs, we excluded outliers exceeding three SD above the mean.

RIF

A 2 (condition: retrieval practice, extra study) × 2 (item type: Rp−, Nrp1) ANOVA examined RIF. With regard to RTs, the main effect of item type was not significant, $F(1, 62) = 3.16$, $p = .080$, whereas the main effect of condition approached significance, $F(1, 62) = 3.90$, $p = .053$. More importantly, the interaction was significant, $F(1, 62) = 6.47$, $p = .014$, $\eta_p^2 = .09$. Separate *t*-tests per condition showed that RTs for Rp– items were significantly longer than RTs for Nrp1 items in the retrieval-practice condition, $t(31) = 2.87$, $p = .007$, $d_z = 0.49$, but RTs for Rp– and Nrp1 items did not significantly differ in the extra study condition, $t(31) = 0.58$, $p = .566$ (Figure 2). With regard to the number of recalled items, the main effect of item type was not significant, $F(1, 62) = 2.42$, $p = .125$, neither was the main effect of condition, $F(1, 62) = 1.98$, $p = .165$. There was a marginal interaction, $F(1, 62) = 3.38$, $p = .071$.

Rp+ enhancement

A 2 (condition: retrieval practice, extra study)×2 (item type: Rp+, Nrp2) ANOVA examined Rp+ enhancement. With regard to RTs, the main effect of item type was significant, $F(1, 62) = 17.51$, $p < .001$, $\eta_p^2 = .22$, whereas the main effect of condition was not significant, $F(1, 62) = 0.06$, $p = .801$. The interaction was not significant either, $F(1, 62) = 1.98$, $p = .164$. With regard to the number of recalled items, the main effect of item type was not significant, $F(1, 62) = 1.12$, $p = .293$, neither was the main effect of condition, $F(1, 62) = 2.94$, $p = .092$, nor the interaction, $F(1, 62) = 1.68$, $p = .200$.

Correlation of RIF and Rp+ enhancement

For additional analyses, we computed RIF as the difference in RTs for Rp– items and Nrp1 items (Rp−−Nrp1) and Rp+ enhancement as the difference in RTs for Nrp2 and Rp+ items (Nrp2 − Rp+). There was no correlation between RIF and Rp+ enhancement in the retrieval-practice condition ($r = -.081$, $p = .661$), nor between the corresponding measures in the extra study condition ($r = -.055$, $p = .765$).

Discussion

RIF occurred as a consequence of selective retrieval practice, whereas selectively practicing SFM without retrieval did not induce forgetting of related SFM. Still, both kinds of practice strengthened Rp+ items. Indeed, the facilitation for Rp+ items did not occur with regard to the number of recalled items but only for RTs. Therefore, the strengthening might seem somewhat weak. However, it has been shown that RIF also occurs with relatively weak Rp+ enhancement, as well as that RIF even occurs with impossible retrieval-practice trials, that is, in the absence of any strengthening (Storm, Bjork, Bjork, & Nestojko, 2006; Storm & Nestojko, 2010). Moreover, RIF also occurred in RTs but not with regard to the number of recalled items in the present experiment. Hence, the results show that strengthening Rp+ items does not suffice to induce forgetting of related motor sequences. However, it is possible that the extra study condition did not induce forgetting because it did not affect motor programmes. Previous investigations found evidence for retrieval practice to affect motor programmes (Tempel & Frings, 2014b, 2015). If RIF is a consequence of interference during retrieval practice, extra study might not have induced forgetting because competition between motor programmes was less strong than during retrieval practice. Perhaps, extra study did not suffice to entail competition between motor programmes of practiced and non-practiced items during practice or at test causing forgetting. Therefore, we examined whether a different kind of practice focusing more on the motor programme would not entail RIF either but only strengthen practiced items in a second experiment.

EXPERIMENT 2

Again, retrieval practice was contrasted with extra study. However, the kind of study was changed. Instead of only entering a SFM once in response to the corresponding animation, participants had to immediately repeat the execution of SFM 10 times in response to its animation. Thus, the practice focused especially on executing the motor response. Moreover, there were two extra study conditions comprising a different amount of practice cycles. A further change pertained to the item material. RIF and Rp+ enhancement occurred in RTs in Experiment 1, but they did not with

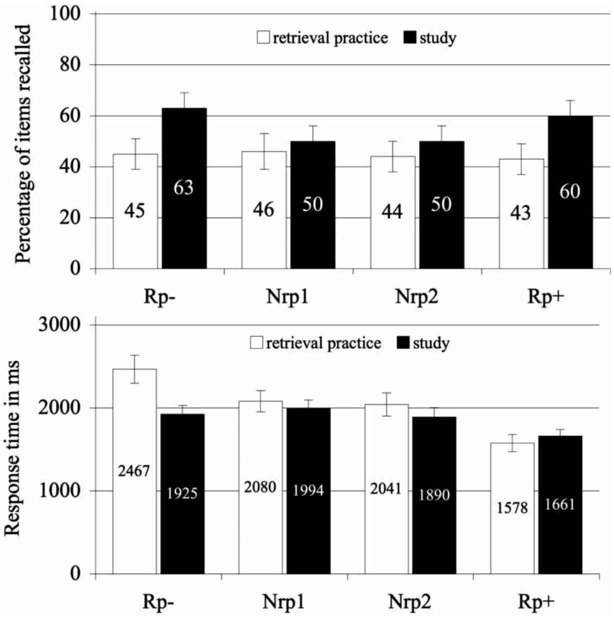

Figure 2. The upper section shows the percentages of items recalled in the final test phase of Experiment 1 as a function of experimental condition and item type. The lower section shows mean response time (in ms) in the final recall test. Error bars depict standard error of the mean. *Rp+*, *practiced items; Rp−*, *unpracticed items of the practiced hand; Nrp1*, *RIF baseline; Nrp2*, *Rp+ enhancement baseline.*

regard to the number of recalled items. Although, we had found previously that RTs are, in fact, a more reliable dependent variable (Tempel & Frings, 2013) to assess both effects, we changed to items that might be suited better for showing RIF and Rp+ enhancement also in the number of recalled items. For this purpose, we turned to material used in Experiment 3 of the study by Tempel and Frings (2013) where both effects occurred with regard to the number of recalled items. Again, the items were six SFM with fingers of the right and six SFM with fingers of the left hand. The hands served as categories, that is, the three Rp+ items and the three Rp– items pertained to the same hand, whereas Nrp1 and Nrp2 items pertained to the other hand. The three SFM of one item type all started with the same finger. This regularity may allow for retrieval dynamics operating within sets of items to have a stronger impact also on the successful recall and not only affect retrieval latency. Confining all items of one item type to the same starting finger probably reduces inter-item integration between item types which is known to counteract the dynamics causing RIF (Anderson, Green, & McCulloch, 2000; Anderson & McCulloch, 1999). We expected to replicate the finding of Experiment 1 that only retrieval practice would impair subsequent recall of Rp– items.

Method

Participants

Ninety-six psychology students at the University of Trier (75 women, mean age = 22.5, SD = 2.8) participated in the experiment. They received course credit for their participation.

Design

Participants were randomly assigned to one of three conditions. The retrieval-practice condition involved the retrieval of Rp+ items during the selective practice phase, whereas the two extra study conditions involved selectively practicing Rp+ items by entering the SFM in response to the corresponding animation 10 times in a row. The short study condition comprised two practice cycles. The long study condition comprised four practice cycles. Item type (Rp–, Rp+, Nrp1, Nrp2) was manipulated within subjects.

Material and procedure

The items again were SFM. However, we used different item sets. For both hands, all two-finger movements started with one out of two fingers. Combining these starting fingers with all three remaining fingers resulted in the six items used for each hand. We counterbalanced if the starting fingers were the index fingers and the ring fingers or the middle fingers and the pinkies (see Appendix B). A further difference pertained to the keys used for input. The fingers of the right hand were placed on the keys 7, 8, and 9, and + of the numeric keypad on the right side of the keyboard, instead of the keys *U*, *I*, *O*, and *P*. The procedure was identical to Experiment 1, with the exception of the practice phase in the extra study conditions. Participants had to execute a SFM 10 times in a row in response to its corresponding letter accompanied by the same animation graphic display as in the learning phase. First, the animation graphic depicting the SFM appeared together with the corresponding letter stimulus in the same fashion as in the learning phase. Then, the participants had to execute the just displayed SFM 10 times. After entering the SFM 10 times, a next SFM was practiced. Instructions additionally emphasised that participants were supposed to use this extra study opportunity to memorise the practiced items especially good for the later test. Whereas the short study condition comprised two practice cycles, the long practice condition comprised four cycles.

Results

Mean retrieval success in the selective practice phase of the retrieval-practice condition was 57% (SD = 29%). For analyses of RTs, we excluded outliers exceeding three SD above the mean.

RIF

A 3 (condition: retrieval practice, short extra study, long extra study)×2 (item type: Rp–, Nrp1) ANOVA examined RIF. With regard to RTs, neither the main effect of item type was significant, $F(1, 93) = 1.28$, $p = .261$, nor the main effect of condition, $F(1, 93) = 0.60$, $p = .551$, whereas the interaction was significant, $F(2, 93) = 3.46$, $p = .036$, $\eta_p^2 = .07$. Separate *t*-tests per condition showed that RTs for Rp– items were significantly longer than RTs for Nrp1 items in the retrieval-practice condition, $t(31) = 2.82$, $p = .008$, $d_z = 0.50$, but RTs for Rp– and Nrp1 items did not significantly differ in the short study condition, $t(31) = 0.42$, $p = .680$, or in the long study condition, $t(31) = 0.43$, $p = .671$. With regard to the number of recalled items, the main effect of item type was not significant, $F(1, 93) = 1.39$, $p = .242$, neither was the main effect of condition, $F(2, 93) = 0.96$, $p = .386$. The interaction was significant, $F(2, 93) = 4.50$, $p = .014$, $\eta_p^2 = .09$ (Figure 3). Separate *t*-tests per condition showed that significantly fewer Rp– than Nrp1 items were recalled in the retrieval-practice condition, $t(31) = 3.63$, $p = .001$, $d_z = 0.64$, but there was no significant difference between Rp– and Nrp1 items in the short study condition, $t(31) = 1.14$, $p = .263$, or in the long study condition, $t = 0$.

Rp+ enhancement

A 3 (condition: retrieval practice, short extra study, long extra study)×2 (item type: Rp+, Nrp2) ANOVA examined Rp+ enhancement. With regard to RTs, the main effect of item type was significant, $F(1, 93) = 11.98$, $p = .001$, $\eta_p^2 = .11$, whereas the main effect of condition was not, $F(2, 93) = 1.80$, $p = .172$. The interaction was not significant either, $F(2, 93) = 1.68$, $p = .192$. RTs for Rp+ items were shorter than RTs for Nrp2 items. With regard to the number of recalled items, the main effect of item type was significant, $F(1, 93) = 5.39$, $p = .022$, $\eta_p^2 = .06$, whereas the main effect of condition was not, $F(2, 93) = 1.63$, $p = .202$. The interaction was not significant either, $F(1, 93) = 0.82$, $p = .443$. More Rp+ than Nrp2 items were recalled.

Correlation of RIF and Rp+ enhancement

We computed two measures each for RTs and for the number of recalled items. RIF was computed as the difference in RTs for Rp– and Nrp1 items (Rp– – Nrp1), as well as the difference in the number of recalled Nrp1 and Rp– items (Nrp1 – Rp–). Rp+ was computed as the difference in RTs for Nrp2 and Rp+ items (Nrp2 – Rp+), as well as the difference in the number of recalled Rp+ and Nrp2 items (Rp+ – Nrp2). With regard to RTs, there was no significant correlation between RIF and Rp+ enhancement in the retrieval-practice condition ($r = .071$, $p = .701$), nor in the short study condition ($r = .330$, $p = .065$), or in the long study condition ($r = .254$, $p = .160$). With regard to the number of recalled items, there was no significant correlation between RIF and Rp+ enhancement either in the retrieval-practice condition ($r = -.174$, $p = .341$), nor in the short study condition ($r = -.044$, $p = .813$), or in the long study condition ($r = .025$, $p = .891$).

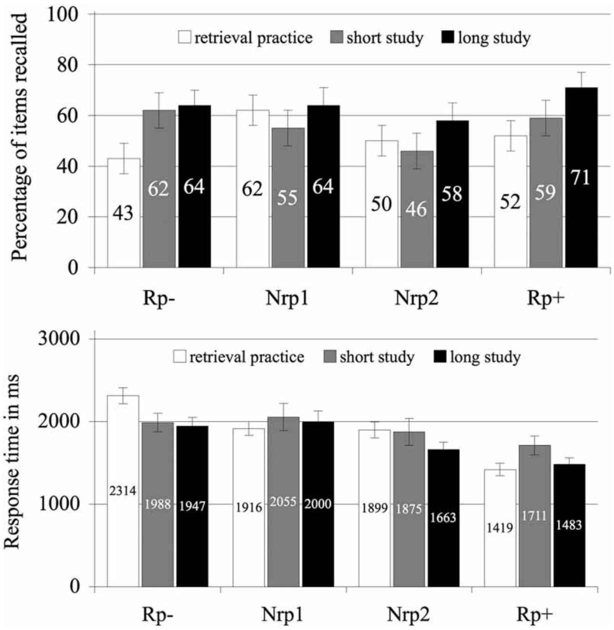

Figure 3. The upper section shows the percentages of items recalled in the final test phase of Experiment 2 as a function of experimental condition and item type. The lower section shows mean response time (in ms) in the final recall test. Error bars depict standard error of the mean. *Rp+, practiced items; Rp−, unpracticed items of the practiced hand; Nrp1, RIF baseline; Nrp2, Rp+ enhancement baseline.*

Discussion

RIF again only occurred in the retrieval-practice condition. Neither the short nor long extra study condition impaired the recall of items belonging to the same hand as the practiced items. This result replicates the finding of Experiment 1. With the use of other item material, RIF and Rp+ enhancement also occurred with regard to the number of recalled items and not only in RTs. We assume that confining all SFM of one item type to start with the same finger reduced inter-item integration and, moreover, might have allowed for facilitation of Rp+ items to occur also with regard to the number of recalled items because this regularity might have permitted a relatively stronger strengthening of the association of motor sequences to their respective letter stimuli.

GENERAL DISCUSSION

Two experiments compared the effects of selective retrieval practice and extra study of motor sequences. Participants first learned SFM. Half of these pertained to the left and the other half to the right hand. Subsequently, participants practiced half of the items of one hand. After a distractor task, finally, memory for all initially learned SFM was assessed. Different variants of selective practice were compared. Experiment 1 contrasted retrieval practice with extra study by means of the same format as in the preceding learning phase, whereas Experiment 2 contrasted retrieval practice with extra study that focused especially on practicing motor programmes. All practice conditions strengthened the practiced items, but only retrieval practice resulted in RIF. The present findings prove the power of retrieval in shaping motor memory. When motor practice does not involve memory retrieval, it does not negatively affect later access to body movements that are related to the practiced movements. Thus, retrieval is essential to trigger dynamics causing RIF. These dynamics may involve inhibition. Retrieval specificity is one of the key predictions of the inhibitory account of RIF that assumes that during retrieval practice of one item the other items of this set interfere in a competition for conscious recollection. In order to resolve this interference, the Rp+ items are strengthened while simultaneously the Rp– items are inhibited. An alternative model assumes that Rp+ items block Rp– items, that is, recall of Rp– suffers from stronger interference in the test phase than Nrp items (Raaijmakers & Jakab, 2013). However, blocking cannot explain the present results because extra study strengthened practiced items as did retrieval practice. This strengthening occurred in the absence of forgetting of SFM of the same hand. Hence, the practiced items did not block access to the non-practiced items. In Experiment 1, there was even a tendency for more Rp– items to be recalled compared to Nrp1 items. In addition, there was no significant correlation between Rp+ enhancement and RIF.

Recently, Jonker, Seli, and MacLeod (2013) challenged the inhibitory account by demonstrating that also a context change between a selective extra study phase and a subsequent test phase can induce RIF-like effects. Therefore, they argue that the assumption of shifts in mental context occurring automatically when participants proceed from the learning phase to the retrieval-practice phase could account for most RIF effects reported in the literature, whereas the non-occurrence of corresponding forgetting effects subsequent to selective extra study resulted from the absence of mental context shifts. For future studies, it might be interesting to investigate if mental context shifts also are able to affect the recall of motor sequences. Of course, this probably would require adjusted context manipulations that are able to impact motor programmes. The necessary groundwork for examining the contribution of mental context to RIF of motor sequences unfortunately is missing so far.

The repetition of learning trials over the course of the learning phase in the present study may suggest that in learning trials occurring at the end of the learning phase participants might have tried to retrieve SFM before the animation graphic display appeared. Such retrieval attempts could have occurred during later blocks of the learning phase as well as during selective extra study. Thus, there might have been a retrieval component to the extra study conditions. However, retrieval was neither required nor reinforced at study trials but the animation graphic display started very shortly after the presentation of a letter stimulus. This short interval hardly sufficed for accessing the corresponding SFM in memory. Instead, the presentation format suggests that retrieval rather was prevented. Moreover, extra study only pertained to three items. From the second extra study cycle on, therefore, items probably could have been accessed in short-term memory more easily, preventing attempts to retrieve SFM from long-term memory via their associated letter stimuli. Most importantly, of course, the significant differences between the retrieval-practice conditions and the extra study conditions indicate that extra study did not represent an equivalent retrieval condition, even though it is not possible to preclude rudimentary retrieval attempts with certainty.

Although we found that RIF of motor sequences is retrieval-specific, as it has been found to be with regard to other learning material, it also depends on peculiar characteristics of motor memory. For example, we have previously found RIF of motor sequences to occur in tests indirectly testing memory by requiring the execution of motor sequences in response to novel test cues (Tempel & Frings, 2014b, 2015). This finding shows that RIF affected motor programmes representing sequences in a format closely corresponding to parameters of movement execution. In addition, the occurrence of RIF required the organised storage into memory sets according to features inherent in the movements, different effectors (Tempel & Frings, 2014a) or movement direction (Tempel & Frings, 2015). Therefore, it is important to take into consideration general prerequisites of RIF, such as retrieval specificity, as well as peculiarities of motor memory in the investigation of retrieval dynamics.

In recent years, memory researchers have strongly advocated the beneficial consequences of testing on retention (e.g., Karpicke & Blunt, 2011; Karpicke & Roediger, 2008). The current conclusion seems to be that testing is one of the most powerful tools for enhancing memory. Although by far the most studies have been concerned with verbal materials, there are a few first investigations now that also reported testing effects in motor action (Boutin et al., 2012, 2013; Kromann et al., 2009). Our present findings imply limits for the application of testing to enhance retention because the observed RIF effects can be considered a side effect of testing. With regard to verbal materials, it has been argued that protecting influences, such as the meaningful integration of facts in school textbooks to be learned, probably preclude RIF in many contexts (Chan, 2009; Chan, McDermott, & Roediger, 2006). However, integration hardly can affect motor action because it involves the activation of semantic representations that do not possess corresponding counterparts in motor memory. Extra study did not induce forgetting but nevertheless strengthened the practiced items. Since extra study and retrieval practice do have such contrary consequences in motor memory, they can be used in a focused manner for different purposes. For example, it seems wise to mainly rely on restudy (thereby preventing retrieval practice) when novel motor sequences are to be acquired. Retrieval practice instead could be used for erasing non-practiced motor sequences, when the goal of practice consists in focusing specific motor actions while weakening unwanted but related motor actions.

We conclude that motor practice does not impair memory for non-practiced body movements when it does not involve retrieval. Hence, exercising does not shape memory by weakening body movements not receiving exercise if exercises do not involve retrieval of body movements. However, practice certainly often does involve retrieval. Then, interference can be triggered that is harmful for the later access to related body movements stored in memory. Training procedures ought to take into account the effects of different kinds of practice. The power of retrieval is a fundamental determinant of motor action.

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APPENDIX A. ITEMS IN EXPERIMENT 1

Hand	*Stimulus*	*First finger*	*Second finger*
Left	a	Middle finger	Index finger
Left	b	Index finger	Ring finger
Left	c	Ring finger	Pinkie
Left	d	Pinkie	Middle finger
Left	e	Middle finger	Ring finger
Left	f	Index finger	Pinkie
Right	u	Index finger	Middle finger
Right	v	Ring finger	Index finger
Right	w	Pinkie	Ring finger
Right	x	Middle finger	Pinkie
Right	y	Pinkie	Index finger
Right	z	Ring finger	Middle finger

APPENDIX B. ITEMS IN EXPERIMENT 2

		Set A		Set B	
Hand	*Stimulus*	*First finger*	*Second finger*	*First finger*	*Second finger*
Left	a	Index finger	Pinkie	Middle finger	Index finger
Left	b	Index finger	Ring finger	Middle finger	Pinkie
Left	c	Index finger	Middle finger	Middle finger	Ring finger
Left	d	Ring finger	Middle finger	Pinkie	Ring finger
Left	e	Ring finger	Index finger	Pinkie	Middle finger
Left	f	Ring finger	Pinkie	Pinkie	Index finger
Right	u	Ring finger	Middle finger	Pinkie	Ring finger
Right	v	Ring finger	Index finger	Pinkie	Middle finger
Right	w	Ring finger	Pinkie	Pinkie	Index finger
Right	x	Index finger	Pinkie	Middle finger	Index finger
Right	y	Index finger	Ring finger	Middle finger	Pinkie
Right	z	Index finger	Middle finger	Middle finger	Ring finger