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Suppression-induced forgetting of motor sequences

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ABSTRACT

Two experiments examined the effects of deliberately suppressing retrieval of motor sequences on their later recall, in the *think/no-think* paradigm (Anderson & Green, 2001). After several motor sequences had been associated with individual cues through repeated practice cycles, a subset of these sequences was retrieved in response to their respective cues (*think* trials), whereas other sequences were suppressed. In such *no-think* trials, cues were shown but participants were instructed to withhold the associated motor response and to suppress its recollection. We found that suppressing retrieval impaired later memory performance for the suppressed sequences in comparison to items that were not cued at all after their initial training (*baseline* sequences). Suppression impaired later sequence recall and sequence speed although in different ways depending on the training level: with higher initial training of sequences (Experiment 1), suppression impaired reaction time, but not recall accuracy; with lower initial training (Experiment 2), suppression reduced recall accuracy. Reaction time analyses revealed a consistent slowing of movement execution for suppressed sequences. These findings show that inhibitory control processes engaged during retrieval suppression can influence memory representations of motor actions, by not only reducing their accessibility but also by affecting their execution, once retrieved.

Imagine a soccer player shooting at the goal. Moments before he hits the ball a defender blocks the aimed direction. The player now can stop this already initialized motor sequence and replace it with a new motor sequence in a different shot angle or by stopping the shot. This ability to control overt behavior is based on executive control processes. Inhibitory processes are thought of implementing a response override function, thereby enabling adaptive control over motor actions. Anderson and Green (2001) demonstrated that inhibitory control processes may also contribute to preventing unwanted memories from entering consciousness. They showed that consistently stopping retrieval of unwanted memories made subsequent recall of these memories more difficult.

The *think/no-think* task, an adaptation of the go/no-go paradigm (used to measure the capability to stop a prepotent motor response), examines the consequences of voluntarily stopping memory retrieval. After studying weakly related word-pairs (e.g., flag – sword), participants are trained to recall and say the associated word as fast as possible when the first word is presented. After training, the *think/no-think* task begins. For *think* trials the task is identical to training. For *no-think* trials, however, participants are instructed to not only avoid saying the response word when the cue is presented, but also to stop the associated memory from entering awareness at all. In a final recall test for all items, participants typically recall fewer *no-think* items compared to *baseline* items, which were studied initially, but which did not appear in the *think/no-think* phase. Impaired memory for *no-think* items, known as suppression-induced forgetting (SIF), has been argued to arise because suppressing retrieval entails inhibition of the target's memory representation (Anderson & Green, 2001; see Anderson & Hulbert, 2021, Marsh & Anderson, n.d. for reviews).

Although initially studied in verbal episodic memory tasks, SIF is not restricted to verbal material or even to episodic memory. Indeed, SIF has been demonstrated on a variety of indirect memory tests, including perceptual identification (Gagnepain, Henson, & Anderson, 2014; Kim & Yi, 2013; Mary et al., 2020) or conceptual priming (Hertel, Maydon, Ogilvie, & Mor, 2018; Taubenfeld, Anderson, & Levy, 2019; Wang, Luppi, Fawcett, & Anderson, 2019). According to the reinstatement principle (Gagnepain, Hulbert, & Anderson, 2017; Hu, Bergstrom, Gagnepain, & Anderson, 2017), disruptions to implicit memory for suppressed content should arise for the content that gets reactivated by cues on a given trial, including sensory, semantic, and emotional aspects

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Abbreviations: SIF, Suppression-induced forgetting.

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of an experience. Consistent with this principle, suppressing retrieval down-regulates hippocampal activity together with fusiform cortex, parahippocampal cortex, or the amygdala, depending on whether objects, scenes, or emotional content are suppressed (see, e.g., Gagnepain et al., 2017; Gagnepain et al., 2014). If retrieval suppression can be flexibly targeted at regions of the neocortex representing specific types of content, suppressing retrieval of motor actions might affect motor cortex. Suppression of motor cortical regions should disrupt motoric features representing movement execution of practiced responses, potentially revealing the existence of *motor SIF*.

If motor SIF occurs, retrieval suppression should inhibit movement representations when reminders of to-be-suppressed items elicit motor sequences associated to them. Several lines of work support this hypothesized extension of SIF to motor actions. First, inhibition in memory shares functional similarities with motor-response inhibition, both occurring when responses are voluntarily stopped in response to a cue (Anderson & Green, 2001). At the level of neural systems, evidence suggests that retrieval and action stopping activate a common domain-general stopping mechanism (Anderson & Hanslmayr, 2014; Apšvalka, Ferreira, Schmitz, Rowe, & Anderson, 2022; Castiglione, Wagner, Anderson, & Aron, 2019; Depue, Orr, Smolker, Naaz, & Banich, 2016; Guo, Schmitz, Mur, Ferreira, & Anderson, 2018) that can be targeted at either mnemonic or motor representations. These functional and anatomical similarities suggest that SIF might not be restricted to words or images typically used as items, but also may extend to memory representations of motor sequences. This possibility is further supported by evidence that other memory inhibition phenomena have parallels in motor memory. For example, studies on retrieval-induced forgetting by Tempel and Frings (2013, 2014, 2017) suggest that an inhibitory mechanism resolves interference between motor programs that arises when a subset of motor responses associated with a cue needs to be retrieved. Schmidt, Frings, and Tempel (2021) also recently showed that a set of studied motor sequences can be affected by selective directed forgetting if that set could interfere with other to-be-retained motor sequences. Such findings suggest that inhibitory processes that impair episodic memory can induce forgetting of motor memories as well, whilst also documenting motor-specific properties of these inhibition effects.

To test for the existence of motor SIF, we designed a motor sequence variant of the *think/no-think* paradigm. In this adapted task, participants were trained to execute sequences of finger movements whenever they were prompted with the sequence's paired letter stimulus as a cue. After being trained on 12 such letter-sequence pairings, participants entered the *think/no-think* task. In this task, participants performed trials on which they received the letter cue from one of the learned pairs, presented in either a green or a red font. When the cue appeared in green (the *think* task), participants were asked to recall and perform the associated motor sequence as quickly as possible. When the cue appeared in red, however, (the *no-think task*), participants were asked to not only not execute the paired sequence, but also to fully suppress the sequence from awareness, preventing it from being retrieved for the entire ten second duration of the trial. Each item was either suppressed or retrieved twelve times during the *think/no-think* phase. A final recall test then presented participants with each letter cue and asked them to recall and execute the paired sequence as quickly as possible. If suppressing retrieval inhibits the accompanying motor memory, then the accessibility of *no-think* sequences should decline, compared to that of *baseline* sequences that were trained, but that did not undergo suppression in the interim. If memorized finger sequences exhibit motor SIF, it would suggest that common inhibitory dynamics apply across episodic and motor memory representations.

1. Experiment 1

Participants first studied and practiced executing 12 three-finger sequences as responses to letters. In the subsequent *think/no-think* task, they were cued on *think* trials to recall the relevant sequence and to execute it as fast as possible. For *no-think* items, their task was not only to stop the motor action, but also to suppress any thoughts about the finger order of the cue-related sequence—to stop motor retrieval. After receiving these instructions, the *think/no-think* trials began. *Think/no-think* items were randomly intermixed in each of four blocks. A final cued recall test assessed memory for all items. We expected that retrieval suppression would impair the accessibility of *no-think* items, compared to *baseline* items. Such impairment may be reflected in reduced sequence recall accuracy, as well as slowed sequence retrieval or execution. The dual processor model by Abrahamse, Ruitenberg, De Kleine, and Verwey (2013) assumes that responding with a trained motor sequence to a cue stimulus involves a cognitive and a motor processor. The cognitive processor translates the stimulus into the associated response and loads the motor buffer. Sequence initiation reflects these steps, whereas subsequent sequence execution primarily reflects the motor processor that is assumed to execute loaded movements in an autonomous manner. Therefore, we not only analyzed total reaction times, but also response times for the first keypress (indicating sequence initiation) and for the remaining keypresses (indicating sequence execution) separately.

1.1. *Method*

1.1.1. *Participants*

Sixty students at the Ludwigsburg University of Education (mean age = 23.4) participated in the experiment and were paid 15 Euro each.

1.1.2. *Design*

Item type was manipulated within participants on three levels: *think* (T), *no-think* (NT), and *baseline* (B). Each *item type* comprised three sequences. In addition, three *filler* items were employed for training purposes only. The dependent variables measured were the number of fully correctly recalled sequences, the number of correct first keypresses, the number of trials with correct second and third keypress, reaction time to begin recalling a sequence (first key press), and speed of sequence execution (second and third key press).

1.1.3. *Material*

The items consisted of twelve sequential three-finger movements of the index-, middle-, ring finger and pinkie of the right hand. These items had to be enacted by pressing the keys V, B, N, and M. At the beginning of the sequence, we presented a black drawing of the right hand on a white background in the center of the screen for 700 milliseconds (ms). We then cued each sequence by a consonant displayed for another 800 ms above the hand. Three different fingers subsequently illuminated for 200 ms each, animating the to-be-enacted sequence. The index and ring finger illuminated in yellow, the middle finger and pinkie in blue. After we presented the sequence, the hand and letter cue disappeared and we instructed participants to press the corresponding keys with their right hand, remembering both the sequence and the associated letter. Each finger rested on its respective key during the whole procedure. Wrong keypress orders were indicated by a 800 ms feedback message “falsch!” (English: “wrong!”). Correctly entered sequences were followed by 800 ms blank screen instead. After a further 700 ms blank screen the next trial started (see Fig. 1).

1.2. *Procedure*

The experiment was conducted online. The experimental routine was implemented with the software PsychoPy in Version 3.2 (Peirce, Gray, Simpson, et al., 2019) and uploaded to the pavlovia.org servers. Participants received a hyperlink to access the experiment on pavlovia.org and to run it then via their own internet browser. Simultaneously, the experimenter was connected in a video call via Cisco Webex Meetings.

The experiment consisted of four parts: Study trials, training, *think/no-think* trials, and final cued recall. Participants first joined a Cisco

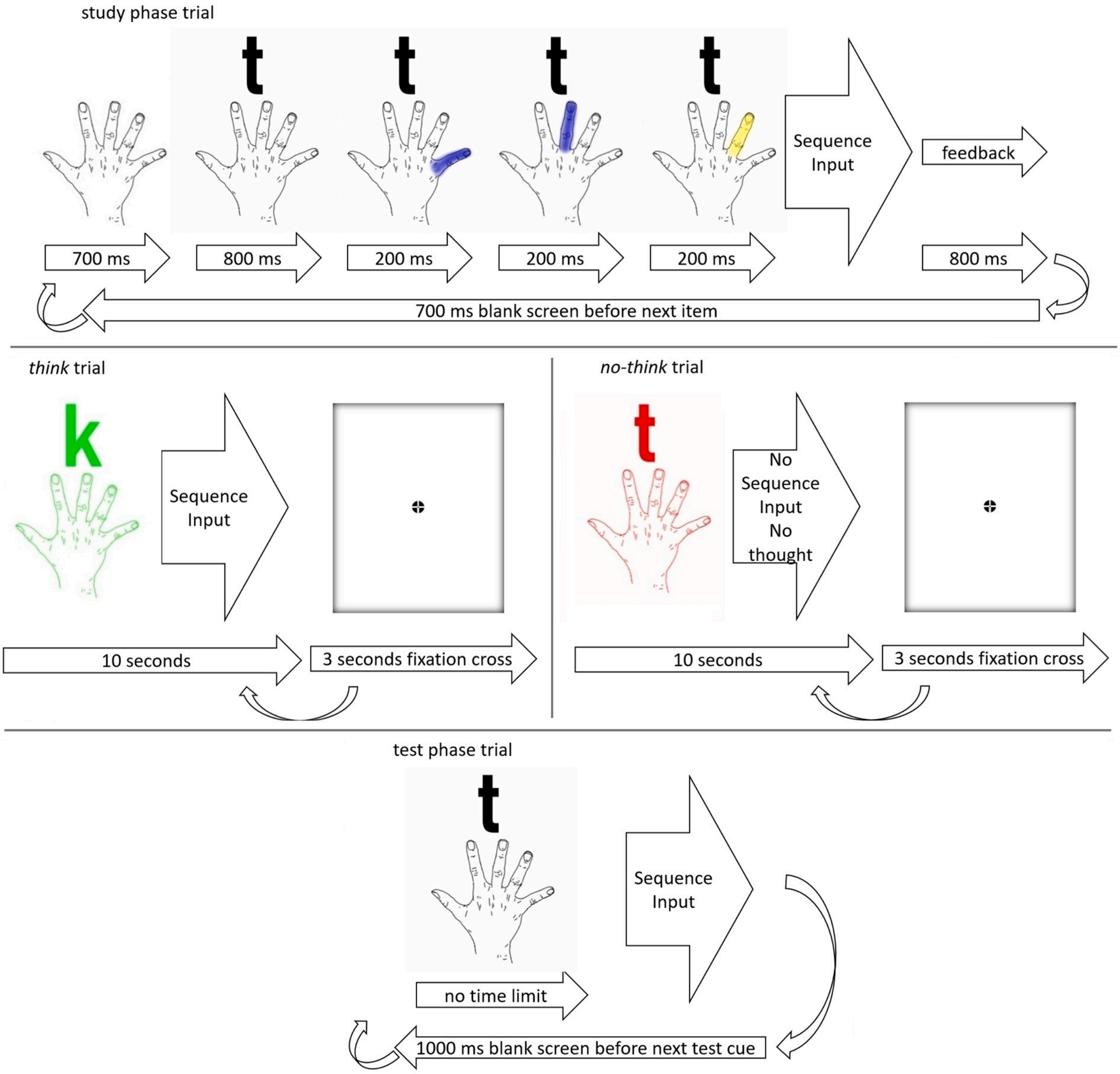

Fig. 1. Schematic diagram for an example trial of the study, *think/no-think* and the final test phases in both experiments. In Experiment 1, the criterion test trial additionally encompassed corrective feedback. A typical final test trial in both experiments is displayed.

Webex session with the experimenter and opened a link to the study trials in their browser. After initial instructions, they received a short example of study trials with *filler* items to familiarize them with the task. Then they received a test for the three *filler* items. After the experimenter had ensured the comprehension of the procedure, study of the experimental items started. The participants` fingers of their right hand rested on the keys V (index finger), B (middle finger), N (ring finger), and M (pinkie) during all study trials. After seven study cycles of the twelve items, the first test was given. Participants were cued with a letter plus the hand drawing and instructed to perform the corresponding sequence. Wrong input was followed by an error message and an immediate presentation of the correct sequence that subsequently had to be performed again. Feedback about the percentage of correctly entered sequences was given after testing all 12 items. If the participant entered nine or more sequences correctly ($\geq 75\%$) the study trials ended. If not, the participant received two further study cycles for the 12 items, followed by a test again. This repeated until the participant reached the criterion or a maximum of 15 study cycles.

Participants then opened a second link to enter the *think/no-think* phase. Instructions explained the two different types of mental and motor responses to *think* or *no-think* items. For items cued in green (*think* items), the task was to recall the sequence belonging to the presented letter and execute it via the keys V, B, N, and M. In contrast, items cued in red (*no-think* items) were not only not to be executed, but also were to be excluded from entering conscious awareness at all. The experimenter ensured the task comprehension verbally. Then two blocks of *think* or *no-think* training with the *filler* items began. After each block, face-to-face feedback ensured the participants' correct task performance; a task-related questionnaire was given about each of the key task elements and directive feedback supplied. The subsequent *think/no-think* trials comprised four blocks intermixing *think* and *no-think* trials, each with a short break before the next one. After two blocks, the task-related questionnaire was administered again, and feedback provided. The final *think/no-think* block was followed by an immediate cued recall test. Each trial presented the same drawing of the hand as before together with a letter cue, both in black. Participants were instructed to execute the corresponding motor sequence via the same keys as used previously (V, B, N and M). After three key presses, a blank screen appeared for 1000 ms before the next trial started. Filler items were cued first, then all nine experimental items in a random order. We divided the experimental items in groups of three that were assigned to each item type once (T, NT or B), resulting in three counterbalancing variations that were randomly assigned to participants.

1.3. Results

To assess the impact of retrieval suppression on sequence memory, we assessed the accuracy of sequence recall and reaction times. Regarding reaction time, only those items were analyzed that had been correctly recalled in the criterion test and in the test phase. Reaction times for the first keypress (initiation time) and reaction times for the second and third keypress of a sequence (execution time) were analyzed. Regarding accuracy, we first analyzed the number of correctly recalled sequences. In addition, we compared the number of trials with a correct first keypress to the number of trials with correct second and keypresses (irrespective of the correctness of the first key). Separate repeated-measures ANOVAs for accuracy and response times examined differences between the three item types, supplemented by planned comparisons of B and NT items as well as B and T items.

A one-factor (item type: NT, B, T) ANOVA examined the number of correct sequences. The main effect was not significant, $F < 1$, neither were pairwise comparisons of B and NT items ($p = .306$) or B and T items ($p = .397$). In a 2 (first keypress, second and third keypresses) x 3 (item type: NT, B, T) ANOVA, there was only a significant main effect indicating that the number of correct first keypresses was higher than the number of correct second and third keypresses, $F(1, 59) = 83.84$, $p < .001$, $\eta_p^2 = 0.59$. The main effect of item type was not significant, $F < 1$, neither was the interaction, $F(2, 118) = 1.49$, $p = .251$.

In contrast to performance on accuracy, the *think/no-think* manipulation had robust effects on reaction time. A 2 (initiation time, execution time) x 3 (item type: NT, B, T) ANOVA examined reaction times. The main effect of item type was significant, $F(2, 84) = 21.48$, $p < .001$, $\eta_p^2 = 0.34$, as was the main effect indicating overall longer initiation than execution time, $F(1, 42) = 138.47$, $p < .001$, $\eta_p^2 = 0.77$. The interaction was significant as well, $F(2,84) = 13.58$, $p < .001$, $\eta_p^2 = 0.24$ (see Fig. 2). Simple effects analyses showed that NT items were initiated significantly more slowly than B items ($p = .002$) that were initiated significantly more slowly than T items ($p < .001$). In addition, the execution time of NT items was significantly longer than the execution time of T items ($p = .002$), whereas the execution time of B items fell in between but differed only marginally from NT items ($p = .058$) and T items ($p = .071$).

1.4. Discussion

Our *think/no-think* manipulation influenced later retention of sequences on the final test. Whereas the initiation of T items was faster than the initiation of B items, the initiation of NT items was slower than the initiation of B items. There was also an effect of item type on execution times. Although only the difference between T and NT items was significant, NT items showed a trend to be slower than B items. Thus, it is unclear whether the execution of T items was facilitated or the execution of NT items suffered or both.

The dual processor model (Abrahamse et al., 2013) assumes that a cognitive and a motor processor are responsible for skilled movement execution. The cognitive processor translates an externally presented stimulus (the letter) into the associated response and may also load the motor buffer with a limited amount of these response elements. This is thought of as happening between stimulus onset and the first keypress. The first keypress, which is typically much slower than those that follow, initiates the sequence, and is assumed to encompass both item selection and execution preparation (i.e., loading of the motor buffer). After motor buffer loading, the motor processor is assumed to execute loaded movements in an autonomous manner. Based on this analysis, reaction times for the second and third keypresses of the present sequence items would primarily reflect movement execution processes, whereas the first keypress would reflect the accessibility of the motor sequence representation in memory. Analysis for these sequence elements for the T and B comparison thus showed more rapid access to the sequence for T items, relative to B items, and a marginally significant slowing of NT items, relative to B items.

In contrast to reaction times, no reliable effects of the item-type manipulation occurred in recall accuracy. Thus, contrary to our predictions, the ability to correctly remember the motor sequence that went with a cue was not reliably affected by either repeated retrieval or repeated suppression. On the one hand, this could reflect an intrinsic difference in the susceptibility of motor representations to forgetting effects induced by inhibition, rendering them qualitatively different from episodic representations that do show such forgetting effects. On the other hand, the presence of reaction time slowing for initiating

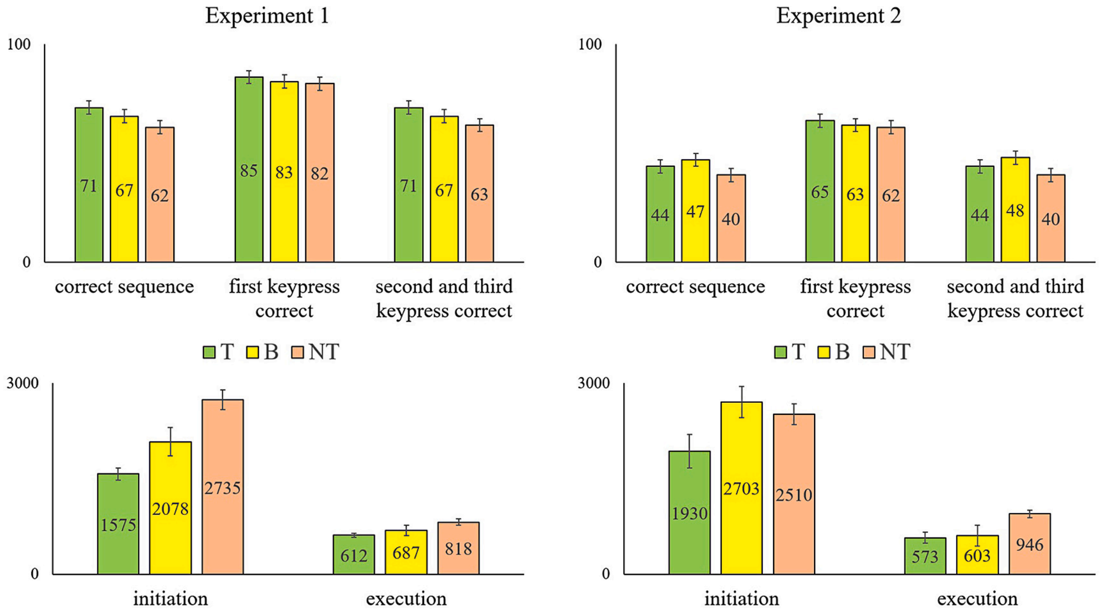

Fig. 2. The upper section of the diagram shows accuracy in percent for the three item types *think* (T), *baseline* (B), and *no think* (NT). The lower section shows response times in milliseconds for initiation and execution of correctly recalled sequences. Error bars represent ±1 S.E.M.

suppressed sequences suggests otherwise. One way of reconciling these discrepant observations may lie in training given to motor sequences. We used a high criterion level of training, requiring at least 75% of the sequences to be learned within a maximum of fifteen learning cycles and five criterion tests. This level of training may have rendered motor sequences more resilient to disruption, with the impact of suppression then primarily expressed in response speed. Thus, it is possible that we failed to observe forgetting for NT items (or enhancement for T items), because our items overall were extremely well trained. To address this possibility, we conducted Experiment 2, in which we altered the procedures of Experiment 1 to reduce overall performance levels.

2. Experiment 2

2.1. Method

2.1.1. Participants

Sixty students (mean age = 22.6) at the Ludwigsburg University of Education participated in the experiment. All students were paid ten Euros each for their participation.

2.1.2. Design

The design was identical to Experiment 1.

2.1.3. Material

The experiment was conducted using PCs with standard German QWERTZ keyboards in a lab at the Ludwigsburg University of Education. The software PsychoPy in version 1.90.1 (Peirce et al., 2019) served for running the experiment. The sequence items were identical to Experiment 1, but we added four more sequential three-finger movements of the index-, middle-, ring finger and pinkie of the right hand, yielding a total of 16.

2.2. Procedure

The experiment consisted of the same four parts as did Experiment 1 (study trials, training, *think/no-think* trials, and final cued recall). Participation in Experiment 2 was not online. After initial instructions and a short example trial for the learning and subsequent (criterion) test trials, participants received five trials of learning for the sixteen items in a random order. Then the first criterion test began. The error message for incorrectly entered sequences was used here again, but the correct sequence was not represented once again after these execution errors. When participants reached a criterion of at least 50% correctly recalled sequences, learning was terminated. Otherwise, participants received another learning trial followed by another test. This repeated until the criterion was reached, or ten learning trials took place. The remainder of the procedure was identical to Experiment 1.

2.3. Results

The same dependent variables were analyzed in repeated-measures ANOVAs and planned comparisons, additionally including the experimenter as a control variable. Whereas the same experimenter had run the experiment with all participants in Experiment 1, five experimenters took part in Experiment 2. We included this control factor in analyses to validate that experimenter effects did not occur.

Unlike in Experiment 1, significant effects of the *think/no-think* manipulation occurred in motor sequence recall accuracy. Whereas there was only a marginal main effect of item type in a one-factor ANOVA examining the number of correct sequences (item type: NT, B, T), $F(2,110) = 1.97$, $p = .087$, $\eta_p^2 = 0.04$, pairwise comparisons showed that significantly fewer NT items than B items were recalled ($p = .035$), whereas the number of recalled T items did not differ from B items ($p = .703$). In addition, there was a significant interaction in a 2 (first keypress, second and third keypresses) x 3 (item type: NT, B, T) ANOVA, $F(2, 110) = 3.84$, $p = .024$, $\eta_p^2 = 0.07$. The number of correct first keypresses did not differ significantly between NT and B items ($p = .913$) or between T and B items ($p = .730$), whereas the number of correct second and third keypresses was significantly lower for NT than B items ($p = .034$) but did not differ significantly between T and B items ($p = .668$).

Regarding reaction times, a significant main effect again indicated longer initiation than execution time, $F(1,32) = 78.65$, $p < .001$, $\eta_p^2 = 0.71$. The main effect of item type was significant as well, $F(2, 64) = 3.39$, $p = .040$, $\eta_p^2 = 0.10$, whereas the interaction was not significant, $F(2, 64) = 2.35$, $p = .104$. Reaction times for T items were significantly shorter than reaction times for B items ($p = .023$), whereas reaction times for NT items did not differ significantly from reaction times for B items ($p = .735$).

2.4. Cross-experiment analyses

Additional analyses collapsed across data from both experiments to examine whether the observed suppression effects were significantly moderated by experiment. Interpretation of the results from these analyses, however, must take into account the differences between experiments. The number of items and the amount of training differed. Experiment 1 was conducted online, Experiment 2 in a lab.

A significant interaction indicated that item type affected the first keypress differently than the second and third keypresses, $F(1, 228) = 5.54$, $p = .004$, $\eta_p^2 = 0.05$. The three-way interaction with experiment was not significant, $F(1, 228) = 1.07$, $p = .342$. The number of correct first keypresses did not differ significantly between NT and B items ($p = .872$) or between T and B items ($p = .881$), whereas the number of correct second and third keypresses was significantly lower for NT than B items ($p = .015$) but did not differ significantly between T and B items ($p = .714$).

Regarding reactions times, a significant interaction indicated that item type affected initiation and execution differently, $F(2, 148) = 4.48$, $p = .013$, $\eta_p^2 = 0.06$. This interaction was not moderated by experiment, $F < 1$. Simple effects analyses showed that T items were initiated significantly more quickly than B items ($p = .002$), whereas B items were not initiated significantly more quickly than NT items ($p = .857$). In contrast, NT items were executed significantly more slowly than B items ($p = .006$), whereas B items were not executed significantly more slowly than T items ($p = .591$).

2.5. Discussion

Procedural changes and a larger number of sequences to learn made learning harder, just as intended. Overall recall accuracy declined substantially as compared to Experiment 1. As predicted, these measures led to SIF in motor recall accuracy, although without an accompanying effect in the speed of movement initiation. Cross-experimental analyses additionally suggested that suppression affected execution speed as well but not initiation speed, whereas the initiation of T items was facilitated. Thus, reaction times may reflect that sequence representations of the NT items suffered because of suppression. Despite the training of T items during *think* trials, the accuracy for T items was not higher as compared to B items. In fact, accuracy for B items was slightly higher than for T items. However, this difference was not significant and we, therefore, hesitate to interpret it as indicating a disadvantage. It is safe to say that no facilitation of T items regarding accuracy was observed. The lack of a facilitation of T items is not unusual in studies with the think/no-think paradigm, however (e.g., Catarino, Küpper, Werner-Seidler, Dalgleish, & Anderson, 2015; Küpper, Benoit, Dalgleish, & Anderson, 2014; Levy & Anderson, 2012; Schmitz, Correia, Ferreira, Prescott, & Anderson, 2017). Yet, there was a facilitation of item initiation. It might be worthwhile considering response speed as a dependent variable in studies with more common material, such as, words or images, as well.

3. General discussion

In two experiments we observed evidence of SIF in memory for motor sequences. In Experiment 1, motor SIF did not show up on our accuracy measure but did occur on measures of the speed of sequence initiation and execution. T items were recalled and executed more quickly than were *baseline* items, which in turn were recalled more quickly than were NT items. Experiment 1 also revealed a trend towards slower execution speed for NT compared to B items. In Experiment 2, we reduced the training given to pairs and increased the amount to be learned to make it more likely to observe a SIF effect in recall accuracy, and indeed found motor SIF on our recall accuracy measure. A comparison of the number of correct first keypresses with the number of correct second and third keypresses suggests that memory for sequences as entities suffered because of suppression. It was not the first element that was affected but the full sequence. This pattern of results suggests that it was not the association with the letter stimulus that was weakened but representations of the sequences became inhibited. Moreover, the sequences were not merely slowed down. The observed effect on correctly recalling the sequences shows that inhibition affected memory not only the speed of execution.

In contrast, for T items as compared to B items, a benefit of movement initiation occurred. In Experiment 1, slower initiation of NT items arose as well. Instead of a significantly slowed movement initiation of NT items, a recall accuracy effect appeared for NT items in Experiment 2. This documents a speed-accuracy tradeoff. When items were memorized sufficiently well, inhibitory control processes probably slowed down access to and execution of stored sequence representations (Experiment 1), but when items were stored less well, voluntary suppression of the item lead to a drop in accurately recalling the item (Experiment 2). The slowing of execution after a sequence has been accessed points to an impact of inhibition on the memory representation itself and not simply on the association of the respective sequences to their stimuli. Moreover, the accuracy with regard to recall of the whole sequence was affected by suppression. Accuracy and reaction-time analyses both suggest, therefore, sequence representations were inhibited, not individual features of these representations.

In the learning trials, all sequences were memorized within one and the same category, the right hand as the common effector. So, all right-hand related motor programs were also activated in the presence of a retrieval cue. This common feature then may have raised an interference potential between these items in the subsequent *think/no-think* practice and task. Studies on retrieval-induced forgetting (Tempel & Frings, 2013, 2017) and selective directed forgetting (Schmidt et al., 2021) suggest that the inhibition process causing those effects depended on the strength of potential interference among motor sequences encoded as one set of items. Future studies may elucidate a potential interference-dependence of *motor SIF* effects as well, for example by comparing different categorizing principles, such as which effectors are involved (e.g., the left versus the right hand). Furthermore, it remains to be examined whether stopping awareness of the sequence was causally necessary for the inhibition effect, or whether stopping the action itself was enough. A similar effect could, in principle, arise with instructions that do not require the avoidance of recollection. This possibility seems unlikely, however, because merely preventing the overt expression of an action still allows it to be retrieved and imagined covertly. A large body of work indicates that covertly retrieving motor actions (i.e., "mental practice") significantly strengthens them and improves their execution (e.g., Agosti & Sirico, 2020; Feltz & Landers, 1983; Feltz, Landers, & Becker, 1988; Lotze & Halsband, 2006). Here, retrieval suppression not only did not strengthen the associated action, but also rendered performance worse than it would have been had cues to the action not been presented at all (*baseline*) during the *think/no-think* task.

In this motor adaption of the *think/no-think* task, we demonstrated a motor analog to SIF, suggesting similar effects of inhibitory control on the retention of traces within different representational systems. The present evidence for *motor SIF* adds to evidence that inhibitory processes contribute to forgetting of motor actions in long-term memory (Schmidt et al., 2021; Tempel & Frings, 2013, 2017). Together this points to a common principle: inhibitory mechanisms act on the very memory representation itself, across modalities, independent of the representational system.

*Publicly available data set:*https://osf.io/xqh4j/?view_only=da175c4e7ae8408aa1478cf8122c2575

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CRediT authorship contribution statement

Markus Schmidt: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing, Visualization. **Michael C. Anderson:** Supervision, Writing – original draft, Writing – review & editing, Conceptualization, Methodology. **Tobias Tempel:** Supervision, Writing – original draft, Writing – review & editing, Conceptualization, Methodology.

Data availability

data is linked public

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