

# The Influence of Poststudy Action Congruency on Memory Consolidation

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**Abstract.** The actions associated with objects are thought to be automatically activated when processing object names. Recent studies, however, have failed to find evidence for a role of the motor system in long-term memory for objects. One exception is a study by van Dam et al. (2013) in which participants studied object names associated with pressing (e.g., *doorbell*) or twisting (e.g., *jar*), followed by pressing or twisting actions in a seemingly unrelated task. In the final memory test, performance for action congruent words was better than for action incongruent words. We aimed to generalize these findings. In Experiments 1 and 2, we found no effect of action congruency on repetition priming in lexical decision and man-made/natural decision. In Experiment 3, the action congruency manipulation was administered immediately after initial study or a day later, just prior to the recognition memory test. We found no effects of action congruency and timing of the action. Finally, Experiment 4 was a direct replication of Experiment 1 of van Dam et al. (2013). Again, we failed to find an effect of poststudy action congruency. Thus, we obtained no evidence for the view that motor actions play a role in long-term memory for objects.

**Keywords:** long-term memory, motor actions, consolidation



Research has suggested that the actions associated with objects are automatically activated during the processing of object pictures and object names (e.g., Tipper et al., 2006). In a variety of tasks, participants respond faster to pictured objects and object names if the response action is congruent with the spatial location of the object handle (Tucker & Ellis, 1998) or with the object's grasp size (Tucker & Ellis, 2001) than if it is not. For example, even though the location of the handle was task irrelevant, participants made faster upright/inverted decisions when the handle location and response side were aligned (e.g., object handle on the left and the participant responded with the left hand) than when they were misaligned (e.g., object handle on the right and the participant responded with the left hand; Tucker & Ellis, 1998). Similar findings have been obtained when participants respond to the color in which an object is depicted (e.g., Bub & Masson, 2010). Grasp compatibility effects have also been obtained with words (e.g., Canits et al., 2018; Tucker & Ellis, 2004). Furthermore, neuroimaging studies suggest that the processing of objects that people interact with (compared to

objects that people do not interact with) results in the activation of brain areas that are associated with motor actions (Buccino et al., 2009; Chao & Martin, 2000; Martin & Chao, 2001; Martin et al., 1996; Rueschemeyer et al., 2010). If indeed the motor actions associated with words and pictures are automatically activated during word or picture processing, action information may become part of memory and affect performance in short-term and long-term memory tasks. Recently, studies have started to address this topic.

Pecher (2013; Pecher et al., 2013) studied the effect of concurrent motor actions on short-term memory performance for manipulable objects and nonmanipulable objects. Manipulable objects (e.g., *comb*, *corkscrew*) are objects that people frequently perform actions on; nonmanipulable objects (e.g., *chimney*, *painting*) are objects that people do not frequently perform actions on. Concurrent motor actions should interfere with the use of motor knowledge in maintaining items in short-term memory. If motor actions support object maintenance in short-term memory, concurrent motor actions should negatively affect memory for manipulable objects more so than for nonmanipulable objects. However, across several experiments using different short-term memory tasks and different concurrent motor tasks, no such effect was found. Quak et al. (2014) manipulated whether the

concurrent motor task was congruent or incongruent with the to-be-remembered words. Motor congruency did not affect short-term memory performance. Although some studies (e.g., Downing-Doucet & Guérard, 2014; Lagacé & Guérard, 2015) have found evidence for involvement of the motor system in short-term memory, such findings were found primarily in situations that promoted the activation and use of the motor system, for example, by presenting videos of hand movements during study (see Zeelenberg & Pecher, 2016, for a review).

Recently, Pecher, Wolters, et al. (2019) performed seven experiments to examine the effects of concurrent motor actions on long-term memory for manipulable (e.g., hammer) and nonmanipulable (e.g., chimney) objects. In none of the experiments was memory for manipulable and nonmanipulable objects differentially affected by the concurrent motor task. In another study (Canits et al., 2018), participants categorized objects that afforded either a power grasp (e.g., *dumbbell*, *zucchini*) or a precision grasp (e.g., *tweezers*, *cherry*) as natural or artifact by grasping cylinders with either a power grasp or a precision grasp. In all experiments, responses were faster when the grasp afforded by the object was compatible with the type of grasp response. However, subsequent memory tasks revealed no better memory for objects for which the grasp was compatible with the grasping response than for objects for which the grasp was incompatible with the grasping response. Related findings, failing to find effects of motor actions on long-term memory for objects, were reported by Guérard et al. (2015).

A recent study, however, suggests that the actions associated with words can under some circumstances affect long-term memory. van Dam et al. (2013) examined memory for words referring to objects that when interacted with would require a pressing action (e.g., *doorbell*, *piano*) or twisting action (e.g., *jar*, *screw driver*). Participants first studied a set of words, some associated with a pressing action and some associated with a twisting action. After initial study, participants performed an intervening number decision task (is the number smaller or larger than five?) that was ostensibly unrelated to the study phase. In this task, half of the participants responded by pressing a response button and the other half responded by twisting a response button. van Dam et al. (2013) hypothesized that repeated pressing or twisting actions performed after initial study, but before the memory test, may reactivate and strengthen matching memory traces, thereby enhancing the consolidation of studied action congruent words. The results of their Experiment 1 were consistent with this idea. In the final recognition memory task, memory for object names that were congruent with actions performed in the intervening task was better than memory for object names that were incongruent with the actions

performed during the intervening task. In Experiment 2, similar findings were found in a variation on a progressive demasking task (Salasoo et al., 1985; Snodgrass & Feenan, 1990). Participants tried to identify pictures that were initially completely masked. Over time, the mask was progressively reduced (every 150 ms, 5% of the initial mask was removed), giving the impression of a picture that gradually emerges from a black background. Participants were instructed to release the response button as soon as they thought they could identify the picture. Both the accuracy and clarification levels (a proxy for speed) at which participants indicated they had identified the picture were measured. Overall, accuracy was higher for action congruent stimuli than for action incongruent stimuli. Experiment 3 used a speeded word fragment completion task. The results showed larger priming effects in response times for action congruent words than for action incongruent words. Thus, the effects of the post-study action congruency manipulation seem to be present in both implicit and explicit memory tasks.

Given that previous short-term memory and long-term memory studies failed to show consistent evidence for involvement of the motor system in memory for object names and pictures, we consider van Dam et al.'s (2013) study highly interesting. Our study has two aims. First, we investigated whether the effects generalize to other implicit memory tasks. To that end, we studied repetition priming effects in lexical decision and man-made decision. Extending van Dam et al.'s findings to these tasks would provide an independent replication of the effect of action congruency on memory performance and additional evidence for van Dam et al.'s suggestion that their findings would generalize to all types of explicit and implicit memory tasks. Second, we investigated how the timing of poststudy actions influences its effect on memory performance. The short-term and long-term memory experiments discussed above suggest that concurrent motor tasks, performed during study or test, do not affect memory performance. Apparently, the timing of motor actions is important. Actions seem to affect later memory performance only when they are performed during the retention interval. van Dam et al. (2013) argued that the intervening action task performed after the initial study of the words influences the memory consolidation process. Memory consolidation is generally assumed to take place over an extended period of time (e.g., Meeter & Murre, 2004; Murre, 1996; Wixted, 2004), and manipulations that affect the consolidation process should have a larger effect when the time between the manipulation and the final test is longer than the one used by van Dam et al. (2013). In our Experiment 3, we therefore used a longer 1-day retention interval and manipulated whether the actions were performed immediately after initial study or a

day later, just prior to the memory task. If repeated poststudy actions affect consolidation, we expected that these actions are particularly influential if they are performed immediately after study.

## Experiment 1

In Experiment 1, we investigated the influence of action congruency on repetition priming in lexical decision. Lexical decision is one of the most commonly used tasks in research on memory and language, and many studies have demonstrated repetition priming effects, that is, faster responses to repeated words, in a lexical task (e.g., Ratcliff et al., 1985; Scarborough et al., 1977; Wagenmakers et al., 2004). van Dam et al. (2013) expected their findings to generalize to all types of implicit memory tasks. The prediction was therefore that a larger repetition priming effect would be found for action congruent words than for action incongruent words. We used a vocal response instead of keypresses to avoid any manual action during test because keypress responses might interfere with (i.e., weaken) the effect of the action congruency manipulation of the intervening action phase.

## Method

### Participants

Sixty participants at Erasmus University Rotterdam participated for course credit. None of the participants participated in any of the other experiments reported in this paper. Participants in all experiments reported in the paper professed to be native speakers of Dutch.

### Stimulus Materials and Apparatus

Stimulus materials were taken from van Dam et al. (2013) and consisted of 24 pressing-related words (e.g., *deurbel* [doorbell], *piano* [piano]), 24 twisting-related words (e.g., *jampot* [jar], *schroevendraaier* [screwdriver]), and 24 neutral nonmanipulable words (e.g., *vijver* [pond], *schutting* [fence]). All stimuli for this and all subsequent experiments are provided in <https://osf.io/z5hj4/>. Note that the stimulus sets used by van Dam et al. (2013) consisted of 25 words per category. We removed one word from each category (i.e., *klavecimbel* [harpichord], *volumeknop* [volume control], *bloementuin* [flower garden]) to have an equal number of stimuli in the studied (old) and nonstudied

(new) conditions. The neutral words served as fillers; they were not included in the analyses because they were not associated with a movement. All stimuli presented in this study were Dutch words, as in van Dam et al. (2013). To ensure counterbalancing of stimulus materials over study status (old vs. new) and intervening action in the number classification task (pressing vs. twisting), four counterbalanced versions were created. Seventy-two pronounceable nonwords were created with the program Wuggy (Keuleers & Brysbaert, 2010) for use in the lexical decision task. Nonwords were matched in length ( $M = 9.4$ ,  $SD = 3.6$ ) to the words ( $M = 9.4$ ,  $SD = 3.4$ ).

In the number classification task of the action phase, the numbers from one to four and six to nine were presented. Two special handmade devices, one with a knob for turning and another one with a knob for pressing, were used for registering responses in the number classification task. The turning knob device was kindly provided by Harold Bekkering, one of the authors of van Dam et al.'s (2013) study. The pressing knob device looked similar to the turning knob, with a similar size knob that required approximately the same force to operate. A voice key was used to register responses in the lexical decision task.

### Procedure

The experiment consisted of three phases, the study phase, the action phase, and the test phase, which were administered in immediate succession, without intervening break. Each phase started with instructions presented on the computer screen. In all phases of the experiment, stimuli were presented in random order; different random orders were generated for each participant. Throughout the experiment, all word and number stimuli were presented centrally in black Courier fonts on a white background. The letter/number height on screen was approximately 0.5 cm.

In the study phase, participants were instructed to memorize the words presented on the screen. Thirty-six words, 12 from each category (pressing-related, twisting-related, or neutral), were presented. Each word was presented for 7,000 ms on the computer screen and preceded by a fixation cross (+) for 500 ms.

The intervening action phase consisted of a go/no-go numerical magnitude classification task. Participants were instructed to respond as fast as possible if the number was larger than five (go trial) but to withhold responses to numbers smaller than five (no-go trial). Each trial started with a fixation cross (+) for 500 ms, followed by the target number presented for a maximum of 2,000 ms. Responses were given by turning or pressing the special knob

described earlier. This action was manipulated between participants, with half of the participants responding by pressing and the other half by twisting. Assignment to the twisting or pressing action was based on the order in which participants were tested using an alternating assignment scheme (twisting, pressing, twisting, pressing, ...). An appropriate twisting movement was made by turning the knob 90 degrees. A pressing response was made by pressing the knob as far as possible. The number disappeared immediately after a response had been made. After number offset, a 500-ms blank screen was presented before the next trial started. The number classification task consisted of 160 trials; each number was presented 20 times.

In the test phase, participants made lexical decisions to letter strings presented on the computer screen. The lexical decision task started with 10 practice trials (5 words and 5 nonwords). Subsequently, 144 letter strings were presented: 36 studied words (12 pressing, 12 twisting, 12 neutral), 36 nonstudied words (12 pressing, 12 twisting, 12 neutral), and 72 nonwords. Each trial started with a fixation cross (+) for 500 ms, followed by the target string. Participants responded by saying “ja” (yes) or “nee” (no). Response latency was measured by a voice key. The target disappeared on response, and the correct response was then displayed in gray at the bottom left of the screen to aid the experimenter who was seated next to the participant and indicated by pressing a numerical key whether the response was correct, incorrect, or a voice key error had occurred. The experimenter’s key press initiated the next trial.

## Results and Discussion

Trials on which a voice-key error occurred were excluded (5.19% of the trials). Mean reaction times (RTs) for correct responses were calculated for each condition and participant. Responses more than 2.5 SDs above or below each participant’s mean RT were excluded from the analyses (2.41% of the correct RTs). The mean RTs and percent errors are shown in Table 1. The complete data and the means on which the analyses are based for this and all subsequent experiments are provided in <https://osf.io/z5hj4/>.

A 2 (studied vs. nonstudied)  $\times$  2 (action congruent vs. action incongruent) repeated measures analysis of variance (ANOVA) on the mean RTs showed a main effect of study status,  $F(1, 59) = 45.53$ ,  $p < .001$ ,  $\eta_p^2 = .44$ , indicating that participants responded faster to studied words than to nonstudied words. No main effect of action congruency,  $F(1, 59) < 0.01$ ,  $p = .991$ ,  $\eta_p^2 = .00$ , nor interaction between study status and action congruency,  $F(1, 59) = 0.04$ ,  $p = .845$ ,  $\eta_p^2 = .00$ , was obtained. Using

**Table 1.** Mean RTs in milliseconds and PEs in Experiment 1 with standard error of the mean in parentheses

Condition	Action congruent		Action incongruent	
	RT	PE	RT	PE
Studied	749 (14.5)	0.00 (0.00)	751 (16.0)	0.42 (0.31)
Nonstudied	811 (20.2)	0.56 (0.27)	810 (20.6)	1.11 (0.42)
Repetition priming	62 (13.1)	0.56 (0.27)	59 (8.6)	0.69 (0.54)

Note. PE = percent error; RT = reaction time.

the JASP software (JASP Team, 2017), we performed a one-sided  $t$ -test with a scale parameter of  $r = 1$  (Schönbrodt et al., 2017) to test if the congruency effect was larger for studied than nonstudied items. The Bayes factor ( $BF_{01} = 8.39$ ) indicated that the data provided more evidence for the null hypothesis of no difference than for the hypothesis that the congruency effect is larger for studied than for nonstudied words.

An ANOVA on the error rates showed a marginally significant main effect of study status,  $F(1, 59) = 3.68$ ,  $p = .060$ ,  $\eta_p^2 = .06$ , indicating that participants tended to make fewer errors to studied words than to nonstudied words. There was also a marginally significant main effect of action congruency,  $F(1, 59) = 3.40$ ,  $p = .070$ ,  $\eta_p^2 = .05$ , indicating that participants tended to make fewer errors to action congruent words than to action incongruent words. Most importantly, no interaction between study status and action congruency was obtained,  $F(1, 59) = 0.07$ ,  $p = .799$ ,  $\eta_p^2 = .00$ . The one-sided Bayesian  $t$ -test also indicated no larger congruency effect for studied than for nonstudied words,  $BF_{01} = 11.94$ . Thus, contrary to the prediction, neither RTs nor error rates indicated that action congruency affected repetition priming in a lexical decision task.

Experiment 1 failed to extend van Dam et al.’s (2013) findings to lexical decision. van Dam et al. (2013, Experiment 2) reported an action congruency effect on performance in a picture identification task, a task they considered sensitive to perceptual priming. Long-term priming in lexical decision similarly depends on non-semantic aspects of stimulus processing. For example, changes in the presentation modality from study to test (e.g., auditory presentation during study, visual presentation during test), compared to the same modality presentation, substantially reduce the size of the repetition priming effect (Kirsner et al., 1983). In addition, prior study of an orthographically dissimilar translation equivalent (English word *frog*) does not result in cross-language repetition priming (Dutch word *kikker*; Gerard & Scarborough, 1989; Kirsner et al., 1980, 1984; Scarborough et al., 1984; Zeelenberg & Pecher, 2003). This contrasts with the finding of cross-language repetition priming in semantic tasks such as animacy and man-made decision tasks (Zeelenberg & Pecher, 2003). Finally, long-term semantic priming is observed in an

animacy decision task, but not in a lexical decision task (Becker et al., 1997; Zeelenberg & Pecher, 2002).<sup>1</sup>

In Experiment 2, we examined repetition priming in man-made/natural decision because this task is considered sensitive to conceptual priming (Zeelenberg & Pecher, 2003). van Dam et al. (2013, Experiment 3) reported an effect of action congruency on priming in word fragment completion, a task they considered sensitive to conceptual priming. Perhaps, conceptual tasks are more sensitive to an action congruency manipulation. Knowledge about how to interact with an object is part of its conceptual representation, and therefore, an effect of poststudy action congruency might be easier to detect in an implicit memory task that requires conceptual processing.

## Experiment 2

### Method

#### Participants

Sixty participants at Erasmus University Rotterdam participated for course credit. None of the participants participated in any of the other experiments reported in this paper.

#### Stimulus Materials and Apparatus

In addition to the 72 words used in Experiment 1, 72 words referring to natural things were selected (e.g., *ijsberg* [iceberg], *lavendel* [lavender]). These words were matched approximately in length ( $M = 9.6$ ,  $SD = 3.4$  and  $M = 8.9$ ,  $SD = 2.3$ ) and log frequency per million (SUBLEX; Keuleers et al., 2010;  $M = 1.57$ ,  $SD = 0.73$  and  $M = 1.57$ ,  $SD = 0.84$ , for natural and man-made words, respectively) to the man-made words from Experiment 1. Half of the natural words were presented in the study phase. The natural words acted as fillers and were not included in the analysis of action congruency effects on implicit memory.

#### Procedure

The experiment again consisted of three phases: the study phase, the action phase, and the test phase. The study phase and the action phase were identical to Experiment 1. In the test phase, participants performed a man-made decision task (instead of lexical decision). Participants responded by saying “ja” (yes) for man-made or “nee” (no)

for natural. Response latency was measured by a voice key and the experimenter registered errors, correct responses, and voice key errors. The man-made decision task consisted of 144 trials: 72 man-made trials (36 studied and 36 nonstudied) and 72 natural trials (36 studied and 36 nonstudied). Most relevantly, the 72 man-made trials consisted of 24 pressing-related words (12 studied and 12 nonstudied), 24 twisting-related words (12 studied and 12 nonstudied), and 24 neutral words (12 studied and 12 nonstudied). Thus, again, depending on the action performed in the number classification task, either the pressing-related or twisting-related words were action congruent.

## Results and Discussion

Trials on which a voice-key error occurred were excluded (5.25% of the trials). Mean RTs for correct responses were calculated for each condition and participant. Responses more than 2.5  $SD$ s above or below each participant's mean RT were excluded from the analyses (2.65% of the correct RTs). The mean RTs and percent errors are shown in Table 2.

A two-factor repeated measures ANOVA on the mean RTs showed a main effect of study status,  $F(1, 59) = 9.93$ ,  $p = .003$ ,  $\eta_p^2 = .14$ , indicating that participants responded faster to studied words than to nonstudied words. No main effect of action congruency,  $F(1, 59) = 0.21$ ,  $p = .651$ ,  $\eta_p^2 = .00$ , nor interaction between study status and action congruency was obtained,  $F(1, 59) = 0.002$ ,  $p = .965$ ,  $\eta_p^2 = .00$ ,  $BF_{01} = 9.52$ .

A two-factor repeated measures ANOVA on the error rates showed no main effects of study status,  $F(1, 59) = 0.25$ ,  $p = .621$ ,  $\eta_p^2 = .00$ , and action congruency,  $F(1, 59) = 0.65$ ,  $p = .424$ ,  $\eta_p^2 = .01$ . A marginally significant

**Table 2.** Mean RTs in milliseconds and PEs in Experiment 2 with standard error of the mean in parentheses

Condition	Action congruent		Action incongruent	
	RT	PE	RT	PE
Studied	821 (19.9)	0.88 (0.45)	817 (18.0)	0.14 (0.14)
Nonstudied	848 (20.2)	0.44 (0.25)	843 (19.5)	0.75 (0.38)
Repetition priming	27 (10.4)	-0.44 (0.24)	26 (14.2)	0.61 (0.41)

Note. PE = percent error; RT = reaction time.

<sup>1</sup> Semantic priming is of course obtained in a lexical decision task when a prime is presented immediately prior to the target (e.g., Neely, 1977; see Pecher, Zeelenberg, & Raaijmakers, 2002, and Balota & Lorch, 1986, for similar findings in masked perceptual identification and pronunciation). However, the presentation of even a single unrelated word between prime and target greatly reduces or eliminates the semantic priming effect (e.g., Dannenbring & Briand, 1982; Masson, 1995).

interaction between study status and action congruency was obtained,  $F(1, 59) = 3.31$ ,  $p = .074$ ,  $\eta_p^2 = .05$ ,  $BF_{01} = 26.42$ . In fact, for studied items, the error percentage tended to be higher in the congruent than incongruent condition, and for nonstudied items, the error percentage tended to be lower in the congruent than incongruent condition. This pattern is opposite to van Dam et al.'s (2013) prediction and results because it suggests that the congruency of the motor action in the filler task had a negative rather than a positive effect on memory. We should add though that the effect on error rates was only marginally significant and error rates were extremely small. Thus, neither RTs nor error rates supported the prediction that action congruency enhances repetition priming in a man-made decision task.

In Experiments 1 and 2, we failed to find evidence for the idea that actions performed after initial study enhance memory performance for action congruent words relative to action incongruent words. One possibility for the lack of an effect in our experiments is that we happened to choose implicit memory tasks that were somehow insensitive to the pressing versus twisting manipulation. It is not clear, however, what mechanisms or principle would underlie such differences across tasks. Given that van Dam et al. (2013) reported action congruency effect in both perceptual and conceptual implicit memory tasks (Blaxton, 1989; Roediger, 1990), one would expect their findings to generalize to the tasks used here, as well as other tasks that are commonly used to study implicit memory such as forced-choice perceptual identification (Ratcliff & McKoon, 1997; Zeelenberg et al., 2002), free association (Weldon & Coyote, 1996; Zeelenberg et al., 1999), and category-exemplar generation (Rappold & Hashtroudi, 1991). Occasionally, however, studies have reported dissociations between different conceptual implicit memory tasks (Cabeza, 1994). Thus, although we cannot rule out that we accidentally selected tasks that were insensitive to the action congruency manipulation, our results are inconsistent with van Dam et al.'s (2013) prediction that their results would generalize to all types of explicit and implicit memory tasks. At the very least, the present findings limit the generalizability of the original van Dam et al. (2013) results.

It is also possible that the implicit memory results of van Dam et al. (2013) were due to explicit retrieval and do not reflect an influence of intervening actions on implicit memory. The tasks that they used (picture identification in a progressive demasking paradigm and speeded word fragment completion) are rather difficult, which may have motivated participants to use explicit retrieval strategies to increase task performance. Moreover, although participants in Van Dam et al.'s study were instructed to respond

as fast as possible, average response latencies were considerably slower (mean RTs > 2,000 ms) than in the tasks used in our Experiments 1 (mean RT  $\approx$  780 ms) and 2 (mean RT  $\approx$  830 ms), possibly leaving room for the influence of explicit retrieval. If the implicit memory results of van Dam et al. (2013) were indeed due to explicit contamination, we should be able to find an effect in an explicit memory task.

The aim of Experiment 3 was twofold. First, we wanted to replicate van Dam et al.'s (2013) findings in recognition memory, a task used in their Experiment 1. Second, we wanted to find additional evidence for the idea that the intervening action manipulation affects consolidation. If actions performed after initial encoding influence consolidation of the studied words, intervening actions are expected to be particularly effective immediately after encoding as compared to when a longer interval elapses in between encoding and the intervening actions. Immediately after study, the consolidation process has only just started and should be relatively susceptible to action congruency manipulations. Also, when a longer time elapses between the manipulation and the memory test, the manipulation has more time to exert its influence on the process of consolidation. In Experiment 3, recognition memory for all participants was tested 1 day after initial study. The intervening action manipulation took place either immediately after initial study or immediately prior to the recognition task.

## Experiment 3

### Method

#### Participants

Eighty participants at Erasmus University Rotterdam participated for course credit. None of the participants participated in any of the other experiments reported in this paper.

#### Stimulus Materials and Apparatus

During the study phase, 12 words from each category (pressing-related, twisting-related, or neutral) were presented for a total of 36 words. During the test phase, 24 words from each category (12 old and 12 new) were presented for a total of 72 words. To ensure counterbalancing of stimulus materials over study status (old vs. new), intervening action in the number classification task (pressing vs. twisting), and timing of the number task (immediate or with a 1-day delay), eight counterbalanced versions were created.

## Procedure

The experiment consisted of three phases: a study phase, an action phase, and a test phase (recognition memory task). The study phase was identical to those in Experiments 1 and 2. The recognition task was administered after a 1-day retention interval for all participants. For half of the participants, the action phase number classification task was administered immediately after the study phase; for the other half, it was administered immediately prior to the recognition task of the test phase.

In the test phase, participants decided for each word whether it had been presented in the study phase or not. Each word was presented on the computer screen until the participant had made a vocal response (“ja” [yes] or “nee” [no]) or until 2,500 ms had elapsed. Each word was preceded by a fixation cross (+) for 500 ms. Response latency was measured by a voice key, and the experimenter registered errors, correct responses, and voice-key errors. A total of 72 words, 36 old and 36 new, were presented in the recognition memory task.

## Results and Discussion

Trials on which a voice-key error occurred were excluded (6.03% of the trials). Hit and false alarm (FA) rates were calculated using the numbers of old and new trials on which the voice-key responded correctly. The dependent variable for memory strength or discriminability that we used was  $d'$  (Macmillan & Creelman, 2005). Note that  $d'$  ( $Z_H - Z_{FA}$ ) is undefined when the hit rate or FA rate is either 1 or 0. We therefore used the Snodgrass–Corwin correction (Snodgrass & Corwin, 1988) to calculate hit (H) and FA rates. Hit and FA rates were calculated as follows:

$$H = \frac{\text{hits} + 0.5}{\text{old trials} + 1}$$

$$FA = \frac{\text{false alarms} + 0.5}{\text{new trials} + 1}$$

For each participant and condition, we calculated the hit rate, FA rate, and  $d'$ . The average across participants for these measures is shown in Table 3 for both the immediate action phase, in which the number classification task was administered immediately after the study phase, and the delayed action phase, in which the number classification task was administered 1 day after the study phase (i.e., immediately prior to the test phase). A two-factor mixed ANOVA with action congruency (congruent vs. incongruent) as a within-subjects factor and action phase delay (immediate vs. delayed) as a between-subjects factor was

**Table 3.** Hit rate, FA rate, and  $d'$  as a function of action congruency and timing of the action phase in Experiment 3

Condition	H	FA	$d'$
Immediate action phase			
Action congruent	.727	.140	1.88
Action incongruent	.748	.127	2.05
Delayed action phase			
Action congruent	.651	.135	1.74
Action incongruent	.688	.141	1.77

Note. All hit rates, FA rates, and  $d'$  values reported in the paper and used in the statistical analyses were based on values obtained after applying the Snodgrass–Corwin correction. FA = false alarm.

performed on the  $d'$  values. We expected to find both a main effect of action congruency and an interaction between action congruency and action delay (i.e., a larger action congruency effect for the immediate action phase group than for the delayed action phase group). The main effects of action congruency and action phase delay were not significant,  $F(1, 78) = 0.97, p = .329, \eta_p^2 = .01$ , and  $F(1, 78) = 1.83, p = .181, \eta_p^2 = .01$ , respectively. A one-sided Bayesian  $t$ -test of the difference between the congruent and incongruent conditions indicated no congruency effect,  $BF_{01} = 21.34$ . The interaction was also not significant,  $F(1, 78) = 0.49, p = .487, \eta_p^2 = .02$ . A one-sided Bayesian  $t$ -test indicated no larger congruency effect for the immediate action phase group than for the delayed action phase group,  $BF_{01} = 9.32$ .

Two one-sample  $t$ -tests showed that  $d'$  values were significantly larger than 0,  $t(79) = 19.31, p < .001$ , and  $t(79) = 20.58, p < .001$ , for the congruent and incongruent conditions, respectively, indicating that recognition performance was above chance.

Experiment 3 failed to show an effect of action congruency on recognition memory. We expected to find an effect of action congruency because van Dam et al.'s (2013) Experiment 1 also tested recognition memory and found better performance for action congruent object names than for action incongruent object names. Moreover, we expected action congruency to be particularly effective when poststudy actions were performed immediately after initial study, as opposed to immediately before the memory test. Such a finding would have been in line with the idea that poststudy action congruency has an effect on memory consolidation. The lack of an effect of action congruency in our study was clearly not due to a floor effect; even after the 1-day retention interval, performance was well above chance. Although, from a theoretical point of view, we expected action congruency to have an effect after a 1-day retention interval, we decided to make a final attempt to find an effect of action congruency on recognition memory. To that end,

Experiment 4 was a direct replication of van Dam et al.'s (2013) Experiment 1 in which the study phase, action phase, and test phase were administered in immediate succession.

## Experiment 4

### Method

#### Participants

Sixty participants at Erasmus University Rotterdam participated for course credit or monetary reward. None of the participants participated in any of the other experiments reported in this paper.

#### Stimulus Materials, Apparatus, and Procedure

Experiment 4 was a direct replication of Experiment 1 from van Dam et al.'s (2013) study. We implemented the following changes, with respect to our Experiment 3, to make Experiment 4 as similar as possible to van Dam et al.'s (2013) Experiment 1. First, the study phase, action phase, and test phase were administered in immediate succession. Thus, the retention interval was much shorter than the 1-day retention interval in Experiment 3, and the timing of the action phase was not manipulated. Second, we changed the number of stimuli presented in the different conditions of the experiment to make these numbers equal to those of van Dam et al. (2013). That is, we used a stimulus set of 25 pressing-related words, 25 twisting-related words, and 25 neutral words. Note that this is the exact same set of Dutch words that was used by van Dam et al. (2013). During the study phase, 15 words from each category were presented for a total of 45 words. During the test phase, 25 words from each category (15 old and 10 new) were presented for a total of 75 words. To ensure counterbalancing of stimulus materials over study status (old, new) and intervening action in the number decision task (pressing vs. twisting), 10 counterbalanced versions were created. Third, throughout the experiment, all word and number stimuli were presented centrally in white Arial fonts on a black background. The letter/number height on screen was approximately 1 cm. Fourth, we made some minor changes to the procedure of the number classification task (action phase) and recognition task (test phase). More specifically, the number of trials was increased to 192; in the recognition phase, participants made decisions by pressing the left (old) or right (new) arrow key on the keyboard (instead of making a vocal response); and if the participant did not respond within 3 s, the word disappeared and below

the position where the word had been presented a message reminding the participant to respond with the left arrow key for "old" and the right arrow key for "new" was presented. This message remained on screen until the participant responded.

#### Preregistration and Open Science

The experiment (method and planned analysis) was preregistered on the Open Science Framework (OSF) (<https://osf.io/jy756/>) on April 12, 2017. The E-prime program used to run the experiment, and all data files can be found on OSF as well. Data collection started on April 26, 2017, and ended on December 5, 2017. The design was approved by Oliver Lindemann, an author on the original study (van Dam et al., 2013).

## Results and Discussion

For each participant and condition, we first calculated hit rates, FA rates, and  $d'$  values in the same way as in Experiment 3. In accordance with our preregistration, two participants with overall  $d'$  score below  $-0.5$  were excluded and replaced by two new participants tested with the appropriate counterbalancing version of stimulus materials. The average hit rates, FA rates, and  $d'$  scores across participants for these measures are shown in Table 4. A paired-samples  $t$ -test showed that the difference in  $d'$  between the congruent and incongruent conditions was not significant,  $t(59) = 1.56$ ,  $p = .124$ ,  $BF_{01} = 1.63$ .

Two one-sample  $t$ -tests showed that  $d'$  values were significantly larger than 0,  $t(59) = 18.47$ ,  $p < .001$ , and  $t(59) = 19.38$ ,  $p < .001$ , for the congruent and incongruent conditions, respectively, indicating that recognition performance was above chance. The lack of an action congruency effect was not due to a floor effect.

In Experiment 4, we again failed to find an effect of action congruency on recognition memory. Thus, despite our best efforts to run an experiment that closely matched van Dam et al.'s (2013) Experiment 1, we failed to replicate their findings.

**Table 4.** Hit rate, FA rate, and  $d'$  as a function of action congruency in Experiment 4

Condition	H	FA	$d'$
Action congruent	.791	.148	2.12
Action incongruent	.782	.164	2.00

Note. FA = false alarm.



## General Discussion

In the four experiments, we investigated the effect of actions performed after initial study on subsequent memory performance. Participants studied words that were associated with a pressing action (e.g., *piano*) and words that were associated with a twisting action (e.g., *key*). After the initial study of the words, in a seemingly unrelated task, participants continuously performed either pressing or twisting actions. Following van Dam et al. (2013), we expected better memory performance to words congruent with the actions performed in the intervening task than to words incongruent with the actions.

In Experiments 1 and 2, we tested the effect of intervening actions on memory in two implicit memory tasks, lexical decision (Experiment 1) and man-made decision (Experiment 2). Although we did find reliable repetition priming effects in both experiments, no interaction between priming and congruency of the intervening actions was observed. The lack of an effect of intervening actions on priming contrasts with the findings reported by van Dam et al. (2013) who reported effects in a picture identification and in a word fragment completion task. At the very least, our findings suggest that van Dam et al.'s (2013) results do not generalize to all implicit memory tasks and are limited in scope. In our Experiment 3, we investigated the effect of intervening action on explicit recognition memory. Because van Dam et al. (2013) argued that actions that are performed after initial study influence the consolidation process, we manipulated the timing of the intervening task. Recognition memory for studied words was tested after a 1-day retention interval. If actions performed after study influence the consolidation of action-related words, the impact of these actions should be larger if they are performed immediately after study, compared to 1 day later, immediately before the recognition task. However, in contrast with a consolidation account, no interaction between action congruency and timing of the intervening action was obtained. Moreover, in contrast to van Dam et al. (2013), no main effect of action congruency on recognition memory performance was found. Experiment 4 was a final attempt to find an effect of action congruency on memory performance. Memory was again tested in a recognition task, but to make the experiment more similar to that of van Dam et al. (2013), the study task, intervening action task, and memory task were administered in immediate succession. Again, we did not find an effect of action congruency on memory performance.

It is difficult to pinpoint why across four experiments we consistently failed to find an effect of poststudy action congruency on memory performance, whereas van Dam et al. (2013) reported significant effects in three experiments. Because we used the same words, in the same language, as van Dam et al. (2013), the stimuli that we used cannot have contributed to our failure to replicate their findings. Based on van Dam et al.'s (2013) results, we hoped to extend their findings to the implicit memory tasks used here. To increase our chances of finding statistically reliable effects, we consistently used sample sizes of at least 60 participants in each of our experiments, which is substantially larger than the sample sizes used by van Dam et al. (Experiment 1:  $n = 21$ ; Experiment 2:  $n = 40$ ; Experiment 3:  $n = 24$ ). We also used consistent, predetermined methods of dealing with outliers. Finally, after failing to find an effect of action congruency in Experiments 1–3, we decided to run a direct replication of van Dam et al.'s (2013) Experiment 1 which we preregistered. In sum, although we did everything we could to find an effect of action congruency, we consistently failed to find an effect.

We also note that the results of van Dam et al.'s (2013) Experiments 2 and 3 are not as convincing as they might seem. First, in their Experiment 2, an effect was found on accuracy, but not on speed of responding (i.e., clarification level). In Experiment 3, the opposite pattern was found; that is, an effect was found on speed of responding, but not on accuracy. Also, the primary analyses of Experiment 3 focused on priming scores (i.e., differences in performance to old and new items), whereas the primary analyses of Experiment 2 focused on overall performance (averaged across old and new items). The latter analysis, however, does not address the question of interest. If intervening actions affect memory consolidation, the effect should be larger for old (studied) than for new (nonstudied) items; that is, an interaction between action congruency and study status is predicted.<sup>2</sup> For Experiment 2, however, no such analysis was reported. Rather, the primary analyses focused on performance across both old and new items. van Dam et al. (2013) performed an additional analysis on only the new items and found no effect of action congruency. This analysis, however, also does not address the question of interest which is whether action congruency had a differential effect on old and new items, an effect that is predicted if actions have an influence on the consolidation process. Thus, the implicit memory results reported by van Dam et al. (2013) provide at best weak evidence for their hypothesis.

<sup>2</sup> Note that an interaction between action congruency and study status is equivalent to a main effect of action congruency on priming scores (i.e., the differences in performance to old and new items).

In the present study, we did not find any evidence to support the hypothesis that the actions associated with objects support long-term memory for object names. Although our findings contrast with van Dam et al.'s (2013) conclusions, we note that other findings also suggest that actions do not play a significant role in long-term memory for object names and pictures of objects (Canits et al., 2018; Guérard et al., 2015). Similarly, findings from our lab have consistently failed to find evidence for a role of the motor system in short-term memory for objects (Pecher, 2013; Pecher et al., 2013; Quak et al., 2014).

Overall, existing evidence for the role of motor actions in long-term memory for objects is very weak. One may wonder why motor information would not support memory for objects. After all, if the motor actions associated with objects are activated during stimulus processing, as is frequently argued (Buccino et al., 2009; Chao & Martin, 2000; Martin & Chao, 2001; Martin et al., 1996; Rueschemeyer et al., 2010; Tucker & Ellis, 1998, 2001, 2004), motor actions might become part of the traces laid down in memory. One possibility is that motor actions are indeed activated, but not stored in memory. Encoding in long-term memory is thought to depend, to a large extent, on attention (e.g., Cowan, 1999; Crabb & Dark, 1999). When participants enact an action described by a stimulus (Engelkamp & Zimmer, 1997), memory is indeed better, suggesting that motor actions strengthen memory (but see McDaniel & Bugg, 2008; Peterson & Mulligan, 2010; Senkfor et al., 2008). However, if attention is focused on aspects of a stimulus other than the actions associated with it (e.g., on spelling and sound, visual features or meaning aspects unrelated to actions), little or no motor information may be maintained in short-term memory and stored in long-term memory. Thus, the motor actions associated with an object may be briefly activated upon presentation of an object, but this activation quickly dissipates if attention is focused on other aspects of a stimulus. It is well known that memory is strongly affected by context (e.g., Barclay et al., 1974; Light & Carter-Sobell, 1970; Pecher et al., 1998; Roediger & Adelson, 1980; Zeelenberg, 2005; Zeelenberg et al., 2003). For example, Barclay et al. (1974) found that “something heavy” is a better retrieval cue for the target word piano if participants studied the sentence “The man lifted the piano” than if they studied the sentence “The man tuned the piano,” and vice versa for the cue “something with a nice sound.” This suggests that not all information associated with a stimulus is stored in long-term memory. Thus, if the context during encoding does not emphasize motor actions, little information related to the actions associated with the stimulus may be stored in memory. As a consequence, motor actions are expected to

play a minimal role in subsequent consolidation and retrieval processes.

Another possibility is that, contrary to what is often claimed, motor actions are not automatically activated during perception. Although many studies have suggested that motor actions are automatically activated during object recognition or word reading, recent studies suggest an alternative interpretation for at least some of the findings that have been put forward to support this claim. Proctor and colleagues (Cho & Proctor, 2010, 2011; Proctor & Miles, 2014) have argued that alignment and grasp compatibility effects (Tucker & Ellis, 1998, 2001) are due to abstract spatial codes. According to this view, alignment and grasp compatibility effects are very much like the standard Simon effect and do not depend on the activation of specific motor actions that specify the arm/hand (left or right) and the type of grasp (e.g., precision grasp, power grasp) that would be used to interact with the presented object. Consistent with an abstract spatial coding account, alignment effects are not only obtained when participants respond with the left and right hand but also when they respond with the left and right feet (Phillips & Ward, 2002; Thomas et al., 2019) or with the index and middle fingers of the same hand (Cho & Proctor, 2010; Thomas et al., 2019). These findings are consistent with the abstract coding hypothesis that predicts an alignment effect for response alternatives that vary on a left-right dimension, regardless of whether the response is made with different hands, different feet, or different fingers on the same hand. These findings, however, do not support the motor-affordance account of alignment effects because it does not predict that the left and right feet or index and middle fingers are differentially activated by object handles that are located on the left or the right of a graspable object. The results of other studies also provide no evidence for the view that the actions afforded by objects are automatically activated during perception (Pecher, Roest, et al., 2019; Roest et al., 2016; Yu et al., 2014).

We conclude by mentioning that we do not argue that memory and action are completely disconnected. Clearly, people can learn new motor skills (Rosenbaum et al., 2001; Willingham, 1998), they possess knowledge about how to interact with objects (Hunnius & Bekkering, 2010; Osiurak & Badets, 2016) and can remember recently performed actions (Wu & Coulson, 2014). The question addressed here and in related studies (Canits et al., 2018; Guérard et al., 2015) is whether the motor actions associated with objects are recruited in an episodic memory task that does not require access to motor knowledge. Our conclusion is that the evidence available to date does not support the idea that motor actions play a central role in long-term episodic memory for objects.

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### History

Received April 4, 2020

Revision received July 8, 2020

Accepted July 15, 2020

Published online October 27, 2020

### Acknowledgments

We thank Wessel van Dam, Harold Bekkering, and Oliver Lindemann for their helpful suggestions and generosity in lending us the twisting response button. We also thank Christiaan Tieman, Marcel Boom, and Gerrit Jan de Bie for their expert technical assistance.

### Open Data

The experiment (method and planned analysis) was preregistered on the Open Science Framework (<https://osf.io/jy756/>). The complete data and the means on which the analyses are based for this and all subsequent experiments are provided in <https://osf.io/z5hj4/>

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