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Effects of memory instruction on attention and information processing: Further investigation of inhibition of return in item-method directed forgetting

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Abstract In the item-method directed-forgetting paradigm, the magnitude of inhibition of return (IOR) is larger after an instruction to forget (F) than after an instruction to remember (R). In the present experiments, we further investigated this increased magnitude of IOR after F as compared to R memory instructions (dubbed the *F > R IOR difference*), in order to understand both the consequences for information processing and the purpose of the differential withdrawal of attention that results in this difference. Words were presented in one of four peripheral locations, followed by either an F or an R memory instruction. Then, a target appeared in either the same location as the previous word or one of the other locations. The results showed that the F > R IOR difference cannot be explained by attentional momentum (Exp. 1), that the spatial compatibility of the response options with target locations is not necessary for the F > R IOR difference to emerge (Exp. 2), and that the F > R IOR difference is location-specific rather than response-specific (Exp. 3). These results are consistent with the view that F > R IOR represents a bias against responding to information emanating from an unreliable source (Taylor & Fawcett, 2011).

Keywords Attention · Memory · Inhibition of return

Understanding how we are able to intentionally forget irrelevant information is critical to understanding how human memory works. Intentional forgetting is studied in the laboratory using a directed-forgetting paradigm. There are variations of this paradigm, and the present experiments focus on the item method (for reviews, see Basden & Basden, 1998; MacLeod, 1998). In this method, participants are presented at study with a list of items (usually words; although see, e.g., Quinlan, Taylor & Fawcett, 2010) one at a time. Each item is followed with equal probability by an instruction to forget (F) or to remember (R). Once all items have been presented, participants are tested for their memory of both F-instructed items (F items) *and* R-instructed items (R items). In both recognition and recall tests of explicit memory, participants typically remember more R than F items, a pattern referred to as a *directed-forgetting effect*. Importantly, this effect does not appear to be due to demand characteristics (MacLeod, 1999).

Historically, forgetting has been viewed as the passive decay of information from memory (Bjork & Geiselman, 1978; Ebbinghaus, 1885). Thus, in the case of intentional forgetting, the directed-forgetting effect was thought to be due solely to preferential elaborate encoding of R items. However, recent studies have shown that in the item-method paradigm, an active process is also associated with instantiating an instruction to forget. Behavioral evidence that responding is slowed after F as compared to R instructions (e.g., Fawcett & Taylor, 2008) suggests that forgetting is more cognitively demanding than remembering. In addition, a plethora of neurophysiological data suggest that an active mechanism is associated with forgetting (Cheng, Liu, Lee, Hung & Tzeng, 2012; Hauswald, Schulz, Iordanov & Kissler, 2011; Ludowig, Möller, Bien, Münte, Elger & Rosburg, 2010; Paz-Caballero & Menor, 1999; Paz-Caballero, Menor & Jiménez, 2004; Ullsperger, Mecklinger & Müller, 2000; van Hooff & Ford, 2011; Van Hooff, Whitaker & Ford, 2009; Wylie, Foxe & Taylor, 2008).

To better understand the active processes involved in intentional forgetting, Taylor (2005) investigated the withdrawal of attention after F and R memory instructions. To do this, she

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combined an item-method directed-forgetting paradigm with a cueing paradigm designed to test for inhibition of return (IOR; Posner & Cohen, 1984). IOR manifests as slowed reaction times (RTs) to targets that appear in the same location as a previous peripheral onset cue, relative to targets that appear in a different location (Posner & Cohen, 1984). Even though IOR is likely generated by the cue onset (e.g., Dorris, Klein, Everling & Munoz, 2002; Klein, 2000; Tian, Klein, Satel, Xu & Yao, 2011), the effect is generally only revealed in RTs once attention has been withdrawn from the location of the initial cue onset (Danziger & Kingstone, 1999). In Taylor (2005), participants were presented with words one at a time either to the left or right of an initial fixation stimulus. The word served as the peripheral onset cue used to generate IOR. Each word was followed by an auditorily presented F or R instruction. Then, after a relatively long stimulus onset asynchrony (SOA; 1,200 ms), a visual target appeared with equal probability either in the same location as the word or in the opposite location. Participants were to indicate the location of the target by making a speeded spatially compatible buttonpress. Taylor found a greater magnitude of IOR after F than after R instructions (F > R IOR). She inferred from this result that attention is more readily withdrawn following F than following R instructions (see also Fawcett & Taylor, 2010).

Endorsing the view that the F > R IOR difference is likely *caused* by the differential withdrawal of attention from F- and R-item representations, Taylor and Fawcett (2011) further investigated this difference to determine the *consequences* that it has for subsequent information processing on F and R trials (see Taylor & Klein, 1998, for detailed discussion of the distinction between causes and effects of IOR). They presented peripheral words, followed by an F or an R instruction, and then by a visual onset target that required a simple detection, a choice localization, or a choice nonspatial discrimination (i.e., determining whether a target triangle was upright or inverted). Across a wide range of SOAs, an F > R IOR difference occurred for the choice localization response, but not for the simple detection or the nonspatial discrimination response. This pattern of results demonstrated that the interaction of memory instruction and IOR did not influence perceptual/attentional processing or response selection stages of information processing. Instead, using the distinction between perceptual and motor “flavors” of IOR (see Chica, Taylor, Lupiáñez & Klein, 2010; Hilchey, Klein & Ivanoff, 2012; Taylor & Klein, 2000), Taylor and Fawcett (2011) argued that the F > R IOR difference reflects a bias against making subsequent responses toward the F-item location. Because the motor “flavor” of IOR is characterized as a bias against responding toward targets that arise in a previously cued location, this conclusion is premised on the notion that the bias—an aftereffect of the peripheral word onset—is enhanced by an intervening F instruction. Taylor and Fawcett suggested that this bias is not necessarily a mechanism by which successful instantiation of the memory instruction is accomplished (although see Fawcett & Taylor, 2010); instead, it may be a consequence of the intention to remember or forget. If so, this would suggest that an F instruction has the immediate effect of ceasing rehearsal of the to-be-forgotten item (see Hourihan & Taylor, 2006), as well as the longer-term effect of biasing subsequent responses away from a source of information that has been deemed unreliable or irrelevant. In this way, an F instruction could influence not only the to-be-forgotten item, but also other information presented in close spatial or temporal proximity with it (e.g., Fawcett & Taylor, 2012).

Although the notion that responses are subsequently biased against the F-item location is an intriguing possibility, a response bias is not the only late-stage mechanism that could account for the F > R IOR difference that occurs for target localization but not for target detection or nonspatial discrimination responses. To understand the consequences that F and R instructions have for subsequent information processing, it is critical to determine whether a response bias is the only viable mechanism that might be operating. The fact that the F > R IOR difference does not occur for a choice discrimination response but does occur for a choice localization response rules out differences in response selection following F and R instructions. However, several other candidate operations must also be ruled out in order to provide a confident understanding of the processing consequences of F and R instructions.

In three experiments, we presented participants at study with a central fixation box surrounded by four peripheral boxes (located in the top right, top left, bottom right, and bottom left of the computer screen). On each trial, a study word was presented with equal probability at one of the four peripheral locations, which was followed by an auditory F or R memory instruction. Then, a visual target requiring a speeded buttonpress response appeared with equal probability at one of the four peripheral locations.

In contrast to previous studies that have assessed the F > R IOR difference using only two word–target locations (Fawcett & Taylor, 2010; Taylor, 2005; Taylor & Fawcett, 2011), we used four word–target locations, which allowed us to differentiate between differences arising from IOR (slowed responses at word locations) and those arising from attentional momentum (speeded responses at locations opposite the word; Pratt, Spalek & Bradshaw, 1999; Snyder, Schmidt & Kingstone, 2001; Spalek & Hammad, 2004)—a distinction not possible when only two locations are used. Using four word–target locations also allowed us to isolate the processing stages that are affected by the differential withdrawal of attention after F and R instructions. Experiment 1 thus determined whether the F > R IOR difference arises primarily due to a *slowed* responding to targets arising in the location of a previous F item or to *speeded* responses at the opposite location. Experiment 2 removed any spatial compatibility between the response options and target locations, to see whether this correspondence was necessary for observing the F > R IOR difference. Finally, in Experiment 3 we assessed whether the F > R IOR difference reflects slowed execution of responses with the particular effector (hand) associated with responses to the location of a previous F item.

Experiment 1

Previous examinations of the F > R IOR difference with target localization have presented participants with a study word to the left or right in the visual periphery, followed by an auditory memory instruction, and then a target to the left or right (Fawcett & Taylor, 2010; Taylor, 2005; Taylor & Fawcett, 2011). The present experiment replicated this general paradigm, but used four word–target locations instead of the typical two. This allowed us to differentiate IOR from attentional momentum (Pratt et al., 1999; Snyder et al., 2001; Spalek & Hammad, 2004) while also providing an independent replication of the F > R IOR effect.

Whereas *IOR* refers to relatively slowed responding to targets that appear at the same location as a peripheral cue/word, *attentional momentum* refers to relatively speeded responding to targets that appear at a location opposite a peripheral cue/word. This speeded responding to opposite targets theoretically occurs because, after attention is removed from the peripheral cue/word, "momentum" carries attention along the line of motion. Because attention is thought to move toward central fixation, due to the fact that this location is equidistant from potential target locations, the momentum that carries attention farther along the vector of motion facilitates target responses at the location mirror opposite the cued location, on the opposite side of central fixation (Pratt et al., 1999). IOR and attentional momentum are independent effects that are potentially additive (see Snyder et al., 2001). As a result, when only two word–target locations are utilized, IOR and attentional momentum are conflated: Relatively longer RTs to targets that appear in the same location as a preceding word may be due to slowed responding at that location and/or to speeded responding at the mirror-opposite location, on the other side of fixation. It thus follows that the F > R IOR difference reported by Taylor (2005; see also Fawcett & Taylor, 2010; Taylor & Fawcett, 2011) could reflect differences in IOR and/or attentional momentum on F and R trials. If attentional momentum could account for the F > R IOR difference, this would be in conflict with the current interpretation of this difference as resulting from relative magnification of the IOR effect by an F instruction, and would suggest that a different mechanism underlies the interaction of memory instructions and the purported IOR effect.

Using four word–target locations allowed us to assess target RTs at locations that were not occupied by the word, but that were also not positioned in the mirror-opposite location on the other side of fixation (in this case, diagonally from) the word location. If there were no RT differences across the three locations where no word was presented, this would counter the suggestion that attentional momentum is responsible for the F > R IOR difference (see Pratt et al., 1999; Snyder et al., 2001; Spalek & Hammad, 2004). If there were such differences in RTs across these three locations, then if the F > R IOR difference persisted even after the location diagonally opposite the target was excluded from the analysis (thereby removing the effects of attentional momentum), this would demonstrate that the magnitude of the IOR effect per se does indeed differ following F and R trials, above and beyond any influence of attentional momentum.

Method

Participants

Twenty participants were recruited from the undergraduate subject pool at Dalhousie University and received one credit point for participating. All of the participants reported normal or corrected-to-normal vision and a good understanding of the English language.

Materials

The experiment used PsyScope 5.1.2 (Cohen, MacWhinney, Flatt & Provost, 1993) on a Macintosh G4-400 computer running OS9. Stimuli were presented on either a 17-in. 1,024 × 768 resolution Macintosh Studio Display color monitor or a 17-in. 1,024 × 768 resolution ViewSonic PT775 color monitor. Responses were recorded using a Macintosh Universal Serial Bus keyboard. The stimuli were presented in Arial 24-point font, as black text against a white background. Participants viewed the computer monitor from a distance of approximately 45 cm.

A master word list of 320 nouns was selected from the Paivio, Yuille and Madigan (1968) Word Pool using an online generator (www.math.yorku.ca/SCS/Online/paivio/). The words had a mean Kučera and Francis (1967) word frequency of 32.4 (ranging from 0 to 100, SD = 34.6), a mean imagery rating of 5 (ranging from 1.8 to 7, SD = 1.4), and a mean concreteness rating of 5 (ranging from 1.2 to 7, SD = 1.9). The words ranged in length from three to 13 letters (M = 7, SD = 2.1). For each participant, custom software randomized this word list and split it into four lists of 20 F items, four lists of 20 R items, and 160 foil items. Two buffer lists of the same five words (ten words total) were used for all participants.

Each trial in the study phase began with the presentation of five identical outline boxes. Each outline box measured 5 × 5 deg of visual angle. One box was centered on the computer monitor. The remaining four boxes were positioned peripherally in the top left, top right, bottom left, and bottom right of the screen. The distance from the center of the middle box to the center of each of the peripheral boxes was 10 deg of visual angle. A fixation stimulus (+) (same font and size as the words) was presented in the middle outline box.

Two auditory tones, one relatively high-pitched (1170 Hz) and one relatively low-pitched (260 Hz), were used as memory instructions. The assignment of memory instruction to tones was counterbalanced, such that half of the participants were told that the high-pitched tone was an F instruction and the low-pitched tone was an R instruction, whereas the other half of the participants were told the opposite (i.e., low tone = F, high tone = R). An asterisk (also same font and size as the words) was used as the target.

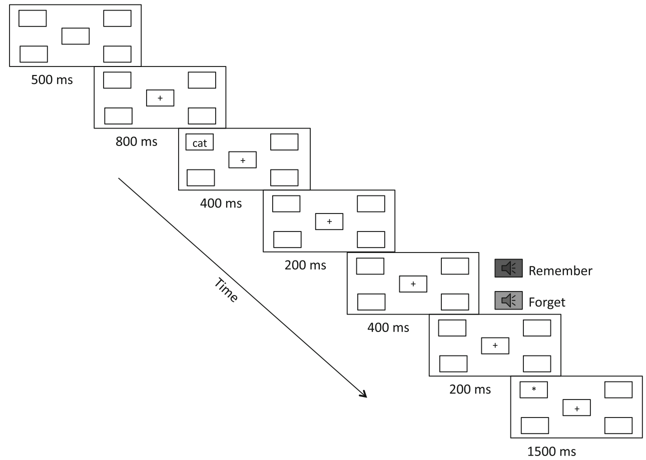

Fig. 1 Depiction of one study phase trial. This figure depicts a "same-location" trial, since the target appears in the same location as the word

Procedure

Participants were given verbal instructions detailing the task, which were reiterated with onscreen instructions prior to participation. The participants were informed that they were to do their best to follow the memory instruction for each word, and that they were to respond to all targets as quickly and as accurately as possible. Participants were told that the study phase would be followed by a memory test, but they were not told that they would be tested for their memory of the F as well as the R items.

Tone familiarization phase Before the experiment began, participants were presented with ten tone familiarization trials. On each trial, a verbal description of the tone–instruction relationship (e.g., "High tone–FORGET") was presented centrally, and remained onscreen for 2,000 ms. The corresponding tone was played over the headphones 500 ms after the verbal description appeared, and lasted for 400 ms. The intertrial interval was 1,000 ms.

Study phase A depiction of each trial is presented in Fig. 1. Five outline boxes (central, top left, top right, bottom left, and bottom right) appeared at the beginning of each trial and remained on the screen for 4,000 ms. A fixation cross ("+") appeared 500 ms after the start of the trial in the center of the central box and remained onscreen until the end of the trial. A word appeared 800 ms after the onset of the fixation cross. The word appeared randomly in the center of one of the peripheral boxes and remained visible for 400 ms. An F or an R memory instruction (high- or low-pitched tone) was presented auditorily 200 ms after the offset of the word, and lasted 400 ms. A target ("*") appeared 200 ms after the removal of the memory instruction. The target appeared randomly in the center of one of the peripheral boxes. Participants were given 1,500 ms from the onset of the target to make a response. They were told to indicate which location the target appeared in by pressing the "f" key with the middle finger of their left hand when the target appeared in the top left location, the "j" key with the middle finger of their right hand when the target appeared in the top right location, the "v" key with the index finger of their left hand when the target appeared in the bottom left location, and the "n" key with the index finger of their right hand when the target appeared in the bottom right location. RTs and accuracy were measured. If the participant did not respond within 1,500 ms of target onset, a message indicating that they had missed was displayed centrally ("Too Slow!").

Four trial types were presented: same location (i.e., word and target appear in the same location), same side (e.g., word appears in top left, target appears in bottom left), across (e.g., word appears in top left, target appears in top right), and diagonal (e.g., word appears in top left, target appears in bottom right). Each type of trial included 20 F items and 20 R items so that, with the ten buffer trials, the study phase consisted of a total of 170 trials.

Each study phase began and ended with five buffer trials, to reduce primacy and recency effects. The buffer trials were identical to the other study phase trials, except that the words were drawn randomly from one of the lists of buffer words, and all buffer words were followed by an R instruction. The words and targets on buffer trials appeared randomly with equal probability in one of the four peripheral locations. Buffer words were not included in the following memory test.

Recognition phase After all study items had been presented, participants completed a yes–no recognition task. All F and R items from the study phase were presented, along with an equal number of foil items. Thus, 160 study items plus 160 unstudied foil items were presented randomly, making a total of 320 trials in the recognition phase. The words were presented centrally on the computer monitor one at a time. Participants were to indicate whether they recognized the word from the study phase. Importantly, they were told to indicate recognition *regardless* of whether they had been instructed to remember or forget the word. If they recognized the word, they were told to press the "y" button, and if they did not, they were told to press the "n" button. After all of the study and foil words had been presented, participants were debriefed and had any questions answered by the experimenter.

Results

Recognition accuracy

To ensure that participants were able to follow the memory instructions presented during the study phase, the data from the recognition test were analyzed using a one-way repeated measures analysis of variance (ANOVA), with word type (F, R, foil) as the independent variable and the proportion of "yes" responses as the dependent variable. We found a significant main effect of word type [$F(2, 38) = 58.022$, $MSE = .011$, $p < .001$], such that R items ($M = .54$) were recognized at a higher rate than F items ($M = .39$) [$t(19) = 4.280$, $p < .001$]. This was the expected directed-forgetting effect (better memory for R than for F items). Both R and F items were recognized at higher rates than foil items ($M = .16$) [$t(19) = 8.632$, $p < .001$, and $t(19) = 9.055$, $p < .001$, respectively].

Target RTs

See Fig. 2 for descriptive statistics. To assess any effects of attentional momentum in both the R- and F-instruction conditions, two one-way repeated measures ANOVAs were conducted with different-location type (same side, across, diagonal) as the independent variable and RTs to respond to the targets as the dependent measure. RTs did not differ between targets appearing at the three different locations in either the F- or the R-instruction condition (all Fs < 1). This suggested that attentional momentum did not play a role in the target RTs on either F or R trials. Thus, to assess differences in IOR, we collapsed the word–target location variable from four levels (same location, same side, across, and diagonal) to two (*same* and *different*), so that RTs for the same-side, across, and diagonal locations were averaged together to produce the *different* condition.

A 2 (word–target location: same, different) × 2 (memory instruction: F, R) repeated measures ANOVA was conducted on target RTs. We found a significant main effect of word–target location [$F(1, 19) = 15.940$, $MSE = 1{,}046.746$, $p = .001$], with slower RTs to targets in the same location as the previous word, as compared to the other locations (an IOR effect). The main effect of memory instruction was not significant ($F < 1$). Finally, we found a significant Word–Target Location × Memory Instruction interaction [$F(1, 19) = 5.410$, $MSE = 563.627$, $p = .031$]. This interaction was due to a greater magnitude of IOR in the F-instruction ($M = 41$ ms) than in the R-instruction ($M = 17$ ms) condition [$t(19) = 2.326$, $p = .031$; see Fig. 3].

Analogous analyses were run on response accuracy. Two one-way repeated measures ANOVAs were conducted with

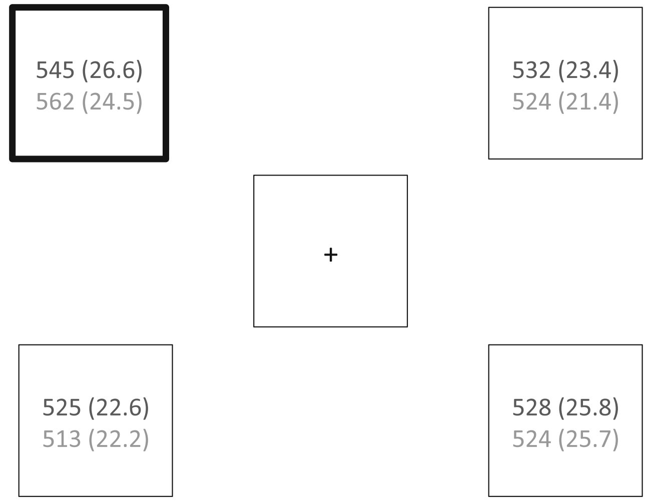

Fig. 2 Descriptive statistics for Experiment 1. The top number in each box shows the mean RT (and *SE*) after a remember instruction. The bottom number is the mean RT (and *SE*) after a forget instruction. For the sake of this depiction, we have represented the data as though the top left location had contained the word, such that the *same* location is the top left box (*bold outline*)

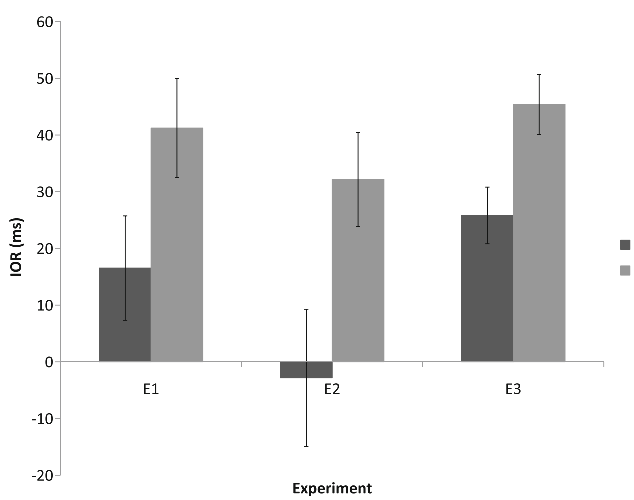

Fig. 3 Inhibition of return (IOR) after remember (R) and forget (F) instructions across all three experiments. Error bars represent *SE*s. IOR is calculated as the RT to targets in *different* locations subtracted from the RT to targets in the *same* location for Experiments 1 and 2 (E1 and E2), and as the RT to targets in the same-side and across locations subtracted from the RT to targets in the *same* location for Experiment 3 (E3)

other-location type (same side, across, diagonal) as the independent variable and accuracy of responses to targets as the dependent measure. No differences were found in either the F- or the R-instruction condition (all Fs < 1). Thus, all further analyses were collapsed across the three different locations, leaving two levels of the word–target location variable: same and different.

In a 2 (word–target location: same, different) × 2 (memory instruction: F, R) repeated measures ANOVA on response accuracy, both the main effects of word–target location and memory instruction failed to reach significance (both Fs < 1). The only significant effect was an interaction [$F(1, 19) = 4.587$, $MSE = .002$, $p = .045$], due to the fact that accuracy tended to be greater when the target appeared in the same location after an R instruction, as compared to when it appeared in a different location [$t(19) = 2.013$, $p = .059$].

Discussion

Experiment 1 replicated the F > R IOR difference in a paradigm with four peripheral locations. Participants were presented with a word in one of four peripheral locations, followed by an F or R memory instruction. Then, a visual target requiring a speeded spatially compatible buttonpress response appeared in one of the four locations. We found a significant directed-forgetting effect, suggesting that participants were successfully able to follow the memory instructions.

An analysis of the target RTs revealed no differences on either F or R trials for responding to targets at the three uncued locations. In other words, since RT was not particularly speeded at the diagonal/opposite location, the results cannot be readily accounted for by attentional momentum. Thus, the F > R IOR difference that we replicated in this experiment is, in fact, due to differences in the IOR effect per se on F and R trials.

Experiment 2

In Experiment 1, we replicated the F > R IOR difference using four locations in a paradigm that required a spatially compatible localization response to report the target. This demonstrated that the pattern of results is, in fact, due to changes in IOR from memory instructions and is not due to interactions of the memory instruction with attentional momentum. Nevertheless, because Experiment 1 required a spatially compatible localization response (see also Fawcett & Taylor, 2010; Taylor, 2005; Taylor & Fawcett, 2011), it remains unclear whether interpretation of the F > R IOR difference as being due to the magnification of the motor "flavor" of IOR by an F instruction as suggested by Taylor and Fawcett is the most parsimonious or accurate account. The present experiment tests an alternative hypothesis that F > R IOR might be due to greater suppression of the abstract spatial code associated with an F item, as per the following rationale based on the Simon effect.

The Simon effect is defined as faster responding when a response is spatially compatible with the target location, rather than incompatible, and occurs even when target location is task-irrelevant (De Jong, Liang & Lauber, 1994; Kornblum, Hasbroucq & Osman, 1990; Metzker & Dreisbach, 2011; Simon, 1969). The Simon effect occurs because the spatially compatible stimulus–response (S–R) code is automatically activated even when it is not task relevant. This automatic activation speeds task-relevant responses when they align spatially, and also slows down task-relevant responses when they conflict.

Interestingly, the Simon effect tends to be observed only on trials that are preceded by a compatible S–R pairing (e.g., Hommel, Proctor & Vu, 2004; Stürmer, Leuthold, Soetens, Schröter & Sommer, 2002; and see Stoffels, 1996, for similar results in a task in which target location was task-relevant). The fact that the Simon effect does not occur after trials on which the task-relevant response conflicts with the compatible S–R code suggests that the automatic activation of compatible S–R codes might be inhibited in some cases—for example, in the face of response conflict (Stürmer et al., 2002). Given that an F instruction operates analogously—even if not identically (Fawcett & Taylor, 2010)—to a stop signal (see Hourihan & Taylor, 2006), it follows that the response conflict generated by an instruction to stop the unwanted commitment of a word to memory may have the effect of suppressing automatic S–R code activation at the F-item location. This is especially true, given that the representation of a peripherally presented F item includes its spatial location (see Hourihan, Goldberg & Taylor, 2007).

To date, all demonstrations of an F > R IOR difference have occurred for localization responses that were spatially compatible with the target location (Exp. 1; see also Fawcett & Taylor, 2010; Taylor, 2005; Taylor & Fawcett, 2011), and not for responses that required a detection or nonspatial discrimination response (Taylor & Fawcett, 2011). We know that IOR can interact with the Simon effect to produce larger effects of S–R compatibility at the cued than at the uncued location (Ivanoff, Klein & Lupiáñez, 2002; Klein & Ivanoff, 2011). It thus follows that reducing the impact of the automatic S–R code activation (normally associated with the Simon effect) should have a greater impact at the cued than at the uncued location. To wit, when a location is made task-relevant by virtue of a spatially compatible localization response, it follows that suppression of the automatic S–R code activation by an F instruction would lead to relatively slower responding to targets that appeared subsequently in the location where the word was presented, rather than elsewhere. This would manifest in behavior as the F > R IOR difference that occurs for spatially compatible localization responses.

To investigate whether F instructions might be suppressing automatic S–R code activation, in Experiment 2 we replicated the methodology of Experiment 1 but eliminated the spatial correspondence between the target locations and response options. This was accomplished by arranging the response options horizontally on the keyboard ("j," "k," "l," and ";"). By requiring what we will refer to as *spatially neutral* responses, we removed the opportunity for spatially compatible S–R code activation to benefit any responses. If the F instruction results in suppression of the automatic S–R code activation, this suppression would not be manifest in the RTs for making these spatially neutral responses. In other words, if the F > R IOR difference is due to suppression of automatic S–R code activation, this pattern should not occur in the results of Experiment 2.

Method

Participants Twenty participants were recruited from the undergraduate subject pool at Dalhousie University and received one credit point for participating. All participants reported normal or corrected-to-normal vision and a good understanding of the English language.

Materials The materials used were identical to those of Experiment 1.

Procedure The procedure was identical to that of Experiment 1, with the exception of the responses required for the target localization task. Instead of indicating where the target appeared by using response keys that were spatially compatible with the target locations, participants' response keys were neutral with respect to the spatial arrangement of the target locations. Specifically, participants were to indicate the location of the target by pressing the "j" key (index finger, right hand) when it appeared in the top left, the "k" key (middle finger, right hand) when it appeared in the top right, the "l" key (ring finger, right hand) when it appeared in the bottom left, and the ";" key (pinkie finger, right hand) when it appeared in the bottom right.

Results

Recognition accuracy To ensure that participants were able to follow the memory instructions presented during the study phase, the data from the memory test were analyzed using a one-way repeated measures ANOVA with word type (F, R, foil) as the independent variable and the proportions of "yes" responses as the dependent measure. We found a significant main effect of word type [$F(2, 38) = 100.477$, $MSE = .009$, $p < .001$], such that R items ($M = .58$) were recognized at a higher rate than F items ($M = .39$) [$t(19) = 6.396$, $p < .001$]. This was the expected directed-forgetting effect (better memory for R than for F items). Both R and F items were recognized at a higher rate than foil items ($M = .15$) [$t(19) = 11.922$, $p < .001$, and $t(19)=9.813$, $p < .001$, respectively].

Target RTs See Fig. 4 for descriptive statistics. To assess any contributions from attentional momentum on F and R trials, we conducted two separate one-way repeated measures ANOVAs, with different-location type (same side, across, diagonal) as the independent variable and RTs to respond to the targets as the dependent measure. RTs did not differ between targets appearing at the three different locations in either the F- or the R-instruction condition (all Fs < 1). Having shown no evidence of attentional momentum in either condition, we averaged across the three different locations, so as to reduce our design to two levels of the word–target location variable: *same* and *different*.

A 2 (word–target location: same, different) × 2 (memory instruction: F, R) repeated measures ANOVA was conducted on the target RTs. Both the main effects of word–target location and memory instruction failed to reach significance (both Fs < 1). The only significant effect was the Word–Target Location × Memory Instruction interaction [$F(1, 19) = 7.895$, $MSE = 775.541$, $p = .011$]. This interaction was due to a greater magnitude of IOR in the F-instruction ($M = 32$ ms) than in the R-instruction ($M = -3$ ms) condition [$t(19) = 2.810$, $p = .011$; see Fig. 3]. In fact, the IOR difference was only significant after an F instruction [$t(19)=3.873$, $p = .001$], and not after an R instruction ($t < 1$).

Analogous analyses were run on response accuracy. Two one-way repeated measures ANOVAs were conducted with other-location type (same side, across, diagonal) as the

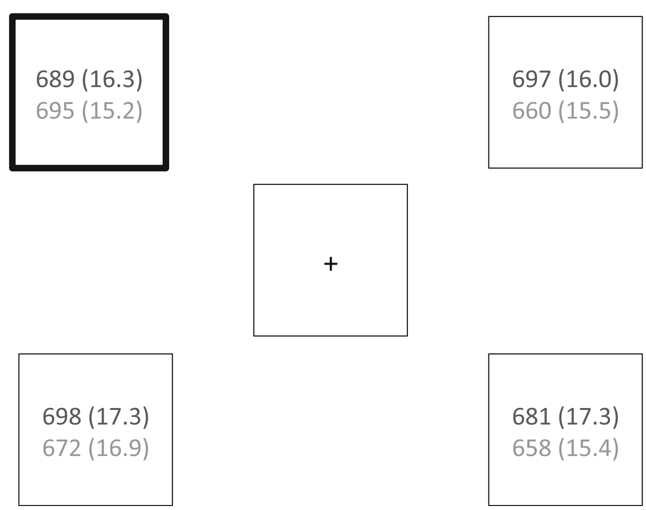

Fig. 4 Descriptive statistics for Experiment 2. The top number in each box shows the mean RT (and *SE*) after a remember instruction. The bottom number is the mean RT (and *SE*) after a forget instruction. For the sake of this depiction, we have represented the data as though the top left location had contained the word, such that the *same* location is the top left box (*bold outline*)

independent variable and accuracy of responses to the targets as the dependent measure. No differences were found in either the F- or the R-instruction condition (all Fs < 1). Thus, all further analyses were collapsed across the three different locations, leaving two levels of the word–target location variable: *same* and *different*.

In a 2 (word–target location: same, different) × 2 (memory instruction: F, R) repeated measures ANOVA on response accuracy, no significant effects were found (all Fs < 1).

Discussion

In Experiment 2, we assessed whether a spatially compatible response is necessary to observe the F > R IOR difference during a target localization task. Participants made a spatially neutral localization response to the target. A significant directed-forgetting effect occurred, suggesting that participants were able to successfully follow the memory instructions. We found no evidence of attentional momentum following either memory instruction, and the magnitude of IOR was greater after F items than after R items.

These results suggest that the response options for the localization task do *not* need to be spatially compatible with the target locations to observe the F > R IOR difference. In fact, a 2 (memory instruction: F, R) × 2 (experiment: 1, 2) mixed ANOVA on the magnitude of IOR showed that the patterns of results were not significantly different between Experiments 1 and 2. Thus, whereas there was a significant difference between the magnitude of IOR after F and R instructions [$F(1, 39) = 14.547$, $MSE = 1{,}561.155$, $p < .001$], we observed no significant effect of experiment, nor an interaction (all Fs < 1). The conclusion from these findings is that the F > R IOR difference is not associated with the suppression of automatic S–R code activation. Rather, any localization response specific to the previous word's location shows a bias when it is F-instructed rather than R-instructed. This is true regardless of whether the response and stimulus locations have any spatial relationship.

Experiment 3

In all previous investigations of IOR and directed forgetting in which the F > R IOR difference has occurred, each potential target location was assigned its own unique response. Thus, another potential alternative hypothesis regarding the F > R IOR difference could be that the differential withdrawal of attention from F and R items results in the slowed execution of responses with the particular effector uniquely associated with the F-item location. In the present experiment, participants indicated on which side of the screen the target appeared by depressing one of two keys, in order to report "left" or "right." This directional response thereby mapped the four peripheral word–target locations onto only two responses, such that the response required for a target that appeared in the same location as the previous item was the same as the response for a target in the other location in the same horizontal hemifield. Thus, the target response was not unique to an individual location. In other words, we required participants to make the same overt responses (left–right) as in previous investigations of F > R IOR (in which only two locations were used), but we expanded the target conditions that elicited these responses. Our question was whether or not RTs to uncued targets that shared a response with cued targets would be similar to those that did not share the same response. If the F > R IOR difference is associated with slowed execution of responses associated with a particular effector (hand, in this case), RTs should be equally slowed at uncued locations that require the same response as the word location.

Method

Participants Sixty-six participants were recruited from the undergraduate subject pool at Dalhousie University and received one credit point for participating. All reported normal or corrected-to-normal vision and a good understanding of the English language.

Materials The materials used were identical to those of Experiments 1 and 2.

Procedure The procedure was identical to that of Experiments 1 and 2, with the exception of the target localization task. Instead of localizing the target with one of four responses, participants were asked to indicate the side on which the target appeared (a distinction with only two possibilities—left or right). When the target appeared on the left, they were to press the "f" key with the index finger of their left hand. When the target appeared on the right, they were to press the "j" key with the index finger of their right hand.

Results

Recognition accuracy To ensure that participants were able to follow the memory instructions presented during the study phase, the data from the recognition test were analyzed using a one-way repeated measures ANOVA with word type (F, R, foil) as the independent variable and the proportions of "yes" responses as the dependent variable. We observed a significant main effect of word type [$F(2, 130) = 258.387$, $MSE = .012$, $p < .001$], such that R items ($M = .60$) were recognized at a higher rate than F items ($M = .43$) [$t(65) = 9.908$, $p < .001$]. This was the expected directed-forgetting effect (better memory for R than for F items). Both R and F items were recognized at higher rates than foil items (M = .17) [$t(65)$ = 18.174, p < .001, and $t(65)$ = 16.846, p < .001, respectively].

Target RTs See Fig. 5 for descriptive statistics. To assess RTs at the uncued locations on F and R trials, we conducted two separate one-way repeated measures ANOVAs, with different-location type (same side, across, diagonal) as the independent variable and RTs to respond to the targets as the dependent measure. Unlike in Experiments 1 and 2, we found a significant effect of different-location type after both the F instructions [$F(2, 130)$ = 4.649, MSE = 837.254, p = .011] and the R instructions [$F(2, 130)$ = 7.879, MSE = 752.050, p = .001]. In both cases, the effect was due to faster RTs occurring at the diagonal location than at the same-side and across locations [after an F instruction, $t(65)$ = 2.899, p = .005; after an R instruction, $t(65)$ = 3.604, p = .001]. This pattern suggested a contribution from attentional momentum on both F and R trials. Critically, however, no significant difference in RTs occurred between same-side and across locations on either F or R trials (all ts < 1).

To provide a measure of IOR that was not contaminated by attentional momentum, we compared RTs at the same location to the average of the RTs at the same-side and across locations, excluding the diagonal location from the analyses. A 2 (word–target location: same, different) × 2 (memory instruction: F, R) repeated measures ANOVA was conducted on target RTs. We observed a significant effect of word–target location [$F(1, 65)$ = 77.699, MSE = 1,076.869, p < .001]. This was due to longer RTs to targets in the same location, as compared to targets at the same-side and across locations (an IOR effect). The main effect of memory instruction did not reach significance (F < 1), but a significant interaction did emerge between word–target location and memory instruction [$F(1, 65)$ = 9.373, MSE = 674.961, p = .003]. Although the magnitude of IOR was significant after both F instructions [M = 45.40 ms; $t(65)$ = 8.555, p < .001] and R instructions [M = 25.81 ms; $t(65)$ = 5.170, p < .001], the interaction was due to a greater magnitude of IOR after F than after R instructions [$t(65)$ = 3.062, p = .003; see Fig. 3].

Analogous analyses were run on response accuracy. In a 2 (word–target location: same, different) × 2 (memory instruction: F, R) repeated measures ANOVA on response accuracy, we found no significant effects (all Fs < 1).

Fig. 5 Descriptive statistics for Experiment 3. The top number in each box shows the mean RT (and SE) after a remember instruction. The bottom number is the mean RT (and SE) after a forget instruction. For the sake of this depiction, we have represented the data as though the top left location had contained the word, such that the *same* location is the top left box (*bold outline*)

Discussion

Experiment 3 determined whether the F>R IOR difference would emerge after a directional response. Participants were presented with a word in one of four peripheral locations, which was followed by an F or an R instruction. Then, a target appeared in one of the four locations, and participants indicated on which side of the screen the target appeared (left or right). The results revealed a significant directed-forgetting effect, demonstrating that participants were able to accurately follow the memory instructions. In addition, we found a significant F > R IOR difference. Critically, RTs to targets that appeared in the uncued location on the same side as the word were statistically equivalent to those that appeared in the uncued location across from the word. Thus, the critical factor in producing relative slowing of RTs to targets at the word location is the correspondence of the location and not the correspondence of the response effector. This fact is consistent with the view that the IOR effect—and, by implication, the F > R IOR difference—is not associated with slowed motor execution at the level of the effector.

Unlike in Experiments 1 and 2, RTs to targets that appeared in the location opposite the word were relatively speeded on both F and R trials, which is indicative of an attentional momentum effect (Pratt et al., 1999; Snyder et al., 2001; Spalek & Hammad, 2004). Importantly, in Snyder et al.'s investigation of attentional momentum, they concluded that attentional momentum, rather than a competing explanation for the differences in RTs that are typically attributed to IOR, is a separable and unique effect that occurs in addition to, but likely has no bearing on, IOR. Even so, we elected to exclude the contributions of attentional momentum from our evaluation of IOR. After having done so, we continued to replicate the F > R IOR difference using the two-alternative directional choice in Experiment 3.

General discussion

The present experiments investigated both the causes and consequences of F > R IOR in item-method directed forgetting. We presented participants with a word in one of four peripheral locations, followed by an F or R instruction, and then a target in one of the four locations. In Experiment 1, participants localized these targets with a spatially compatible buttonpress. Participants were overall slower to respond when the target appeared in the same location as the word rather than the other locations, and the magnitude of this IOR difference was greater following F than following R instructions. We replicated these results in Experiment 2, in which participants localized the targets with a spatially neutral buttonpress. Again, in Experiment 3, the results were replicated with a directional (left vs. right) response. To assess whether the magnitude of this difference in IOR after F and R instructions differed across experiments, we conducted a 2 (memory instruction: F, R)×3 (experiment: 1, 2, 3) mixed ANOVA with the magnitude of IOR as the dependent measure (see Fig. 3).[1] We found a significant main effect of memory instruction [$F(1, 103) = 20.271$, $MSE = 1{,}345.939$, $p < .001$], reflecting the fact that the magnitude of IOR was greater after F than after R instructions. A marginally significant effect of experiment also occurred [$F(2, 103) = 3.007$, $MSE = 2{,}254.405$, $p = .054$]. Critically, the interaction did not approach significance ($F < 1$). Thus, in all three experiments reported here, F > R IOR was observed, and the magnitude of this difference was approximately equal across experiments, also suggesting that the speeded RT at the diagonal location in Experiment 3 (attentional momentum) did not, in fact, modify the F > R IOR difference.

From the findings of Taylor and Fawcett (2011), we know that no significant difference in IOR is found between F- and R-instruction conditions when the target response is a detection or nonspatial discrimination response. This suggests that the difference does not reflect delayed perceptual processing at the location of the F items, nor delayed response choice. We know from the present experiments that the difference does occur when a directional (left–right) response is made to the target, but this increased RT is unique to the word location, and does not generalize to other responses made with the same effector. This suggests that the difference is not associated with slowed response execution specific to the particular effector associated with the F-item location, so F > R IOR likely does not reflect inhibition of motor cortex or very late-stage changes in muscle activity in the fingers (e.g., pulling the finger away from the key). We learned from Experiment 2 that the localization response does *not* have to be made on keys that are arranged in a manner spatially compatible with the stimulus display, suggesting that the difference does not reflect suppression of the automatic activation of spatially compatible S–R codes. Finally, Experiments 1 and 2 confirmed that the F > R IOR difference arises from slowed RTs at the location of a previous F item rather than speeded RTs at the opposite location, and Experiment 3 showed that the effect occurs even if the diagonally opposite location is not included in the analysis. Taken together, our results rule out viable alternative explanations of the F > R IOR difference, and in so doing, converge on the account offered by Taylor and Fawcett (2011).

Adopting the characterization offered by Taylor and Fawcett (2011) and drawing on our present findings, we thus argue that the memory instructions in an item-method directed-forgetting task lead to a differential withdrawal of attention from F and R items, thereby revealing a bias against responding toward targets that arise subsequently at the F- rather than the R-item location. The differential withdrawal of attention likely accounts for the fact that instantiating an F instruction is initially more effortful than instantiating an R instruction (Cheng et al., 2012; Fawcett & Taylor, 2008) and seems to engage frontal mechanisms to cease rehearsal and prevent the commitment of these items to memory (Hsieh, Hung, Tzeng, Lee & Cheng, 2009; Ludowig et al., 2010; van Hooff & Ford, 2011; Wylie et al., 2008). The subsequent bias prevents information from unreliable sources (in this case, location) from repeatedly gaining control over responding, and is reflected in the F > R IOR difference. Insofar as the IOR effect is the result of a mechanism that facilitates a visual search for novelty (Klein, 2000; Klein & MacInnes, 1999; MacInnes & Klein, 2003), the increased delay in responding toward the source of an F item allows information at this location to accumulate and be scrutinized before issuing a response. In this way, the F > R IOR difference may functionally increase the time available for limited-capacity resources to process information that arises from a source that was recently deemed unreliable. In so doing, an F instruction not only limits further processing and commitment of the F item to memory, it also impacts subsequent information processing in the short term (see also Fawcett & Taylor, 2012).

Whether the influence of an F instruction on subsequent information processing reflects a mechanism by which forgetting is accomplished or is a consequence of the attempt to instantiate the instruction is uncertain at present. Whereas Taylor and Fawcett (2011) found no significant relationship between the F > R IOR difference and the magnitude of the directed-forgetting effect, Fawcett and Taylor (2010) found that the F > R IOR difference was driven by trials on which the intention to forget was successful. To further explore this issue, we conducted a simple regression, collapsing the data from all three experiments in order to investigate any possible relationship between the magnitude of the F > R IOR difference and the magnitude of the directed-forgetting effect. In fact, we observed a significant relationship: Larger F > R IOR differences were associated with larger-magnitude directed-forgetting effects in subsequent recognition [see Fig. 6; $r = .255$, $t(104) = 2.684$, $p = .008$—a small- to medium-sized

[1] All of the data were used in this analysis, including the diagonal location in Experiment 3.

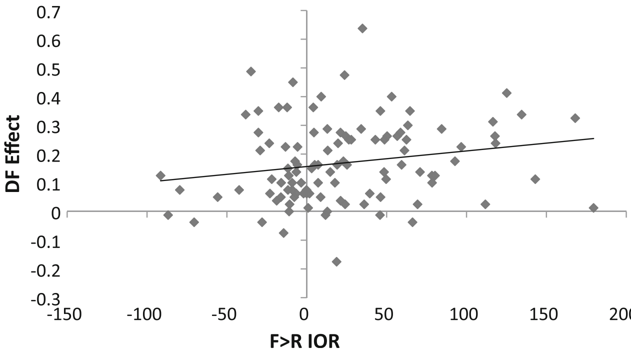

Fig. 6 Scatterplot depicting the relationship between the magnitude of the directed-forgetting effect (proportion of remember [R] items recognized – proportion of forget [F] items recognized) and the magnitude of the F > R IOR difference (F IOR – R IOR) across all three experiments. IOR is calculated as the RT to targets in *different* locations subtracted from the RT to targets in the *same* location for Experiments 1 and 2, and as the RT to targets in the same-side and across locations subtracted from the RT to targets in the *same* location for Experiment 3

effect, per Cohen, 1992]. That said, however, we also conducted a conditional analysis to determine whether the RT on a given trial was associated with later recognition performance for that word. A 2 (memory outcome: remembered, forgotten) × 2 (word–target location: same, different) repeated measures ANOVA was conducted separately for F and R trials, with RT as the dependent measure. In both the F- and R-instruction conditions, only a significant main effect of word–target location occurred, reflecting IOR [$F(1, 105) = 92.249$, $MSE = 2,249.709$, $p < .001$, and $F(1, 105) = 19.052$, $MSE = 2,872.182$, $p < .001$, respectively]. No other effects were significant (all Fs < 1). Thus, we did not find that the magnitude of IOR varied as a function of whether the study item was later recognized at test for either F or R items. These inconsistent findings leave open the possibility that some independent mechanism is at least partially responsible for successful forgetting and that the bias associated with the F > R IOR difference reflects an aftereffect of the F instruction rather than the outcome of a mechanism by which the F instruction is successfully instantiated.

Even if the mechanism that gives rise to the F > R IOR difference is not directly related to the success of instantiating the intention to forget, it may nevertheless contribute indirectly to the effectiveness of the F instruction by limiting the availability of cognitive resources during presentation of the F item. Lee (2012) demonstrated that the effectiveness of an F instruction is inversely related to the availability of cognitive resources, such that automatic encoding of the F item occurs in the absence of a high cognitive load. Conversely, intentional forgetting in an item-method task is more successful when fewer cognitive resources are available for this automatic processing of the F item (see also Lee & Lee, 2011). Thus, intentional forgetting might depend on the removal of processing resources, even if the forgetting is not accomplished by this removal per se. If so, the withdrawal of attention that reveals the F > R IOR difference may not cause intentional forgetting, but may nevertheless set the stage for successful instantiation of the intention to forget.

A withdrawal of processing resources from the F-item representation and a bias against responding to subsequent information presented in close spatial and temporal proximity to the F item might also subserve forgetting indirectly by weakening the episodic trace. It has been fairly well established that the directed-forgetting effect in the item-method paradigm is only apparent in explicit tests of memory, and that no difference between F and R items is seen for implicit tests of memory (Basden, Basden & Gargano, 1993; MacLeod & Daniels, 2000; Van Hooff et al., 2009). According to Racsmány and Conway (2006), explicit tests of memory tap into the episodic memory of the study phase. Conversely, implicit memory tests tap into semantic or lexical representations. Since the directed-forgetting effect is only observed when explicit memory tests are used, the effect could be a result of the modification, degradation, or inhibition of *episodic* information related to the F items (Racsmány & Conway, 2006).

In support of this notion, Hourihan et al. (2007) found that F-item memory was aided significantly by having the word presented in the same location where it had been at study, but that R-item memory was not so affected. This result is consistent with the view that F items have a “shortage” of episodic information, and are thus relatively more difficult to remember than R items. However, when contextual information from study is provided, memory is improved for these episodically impoverished F items. R items already have a rich episodic memory due to elaborative rehearsal at study, and therefore the benefit of repeating contextual information at test is minimal. Characterizing directed forgetting in terms of degradation of the F-item representation also accounts for the fact that directed-forgetting effects occur for detailed but not for gist representations (see Fawcett, Taylor & Nadel, 2013); for the observation that false alarms to unstudied foil items are more often due to misattributions as F items than as R items (Thompson, Fawcett & Taylor, 2011); and for the finding that instructional designation elicits more “don’t know” responses for F than for R items (Goernert, Widner & Otani, 2007).

Considered in this light, our present findings thus suggest that the effects of an F instruction may be multifaceted, leading to potential degradation of the episodic trace—perhaps due to the withdrawal of attention from its representation (see Taylor, 2005; Taylor & Fawcett, 2011)—as well as changes in the processing of items presented subsequently within a short temporal window following the F instruction. These changes may help bias the system against repeatedly responding to information that arises from an unreliable source (Taylor & Fawcett, 2011), while also limiting incidental encoding of information that follows subsequently (Fawcett & Taylor, 2012). In this way, an F instruction influences not only the item to which it refers, but also overt (buttonpress) and covert (incidental-encoding) responses to information that appears shortly thereafter. It is currently unclear whether these effects on subsequent information processing reflect the successful instantiation of an F instruction or an aftereffect of the memory intention that it forms. In any case, it seems likely that—whether directly or indirectly—the processes reflected in the F > R IOR difference enable intentional forgetting by limiting the availability of cognitive resources that would otherwise lead to automatic processing of the F item and/or by weakening the episodic representation of the F item and its links to information that follows shortly thereafter in the same epoch.

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