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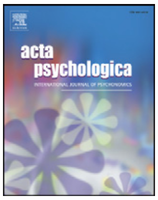

The control of working memory resources in intentional forgetting: Evidence from incidental probe word recognition ☆

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A B S T R A C T

We combined an item-method directed forgetting paradigm with a secondary task requiring a response to discriminate the color of probe words presented 1400 ms, 1800 ms or 2600 ms following each study phase memory instruction. The speed to make the color discrimination was used to assess the cognitive demands associated with instantiating Remember (R) and Forget (F) instructions; incidental memory for probe words was used to assess whether instantiating an F instruction also affects items presented in close temporal proximity. Discrimination responses were slower following F than R instructions at the two longest intervals. Critically, at the 1800 ms interval, incidental probe word recognition was worse following F than R instructions, particularly when the study word was successfully forgotten (as opposed to unintentionally remembered). We suggest that intentional forgetting is an active cognitive process associated with establishing control over the contents of working memory.

1. Introduction

Forgetting has a poor reputation in the eyes of the public — as exemplified by the financial success of services promising to eradicate it altogether. While this may sound laudable, academics (e.g., James, 1950) have long realized that the inability to *suppress* an *undesired* thought or memory may be as troublesome, if not more so, than the inability to *maintain* a *desired* thought or memory indefinitely. In the laboratory, *intentional forgetting* can be studied using an item-method directed forgetting task. Participants are presented with a list of words, one after the other, each followed by an instruction to Remember (R) or Forget (F). During a subsequent memory task in which participants are tested explicitly for *all* study words, participants typically recall or recognize more R words than F words. This difference is known as a directed forgetting effect (see MacLeod, 1998) and cannot be explained by demand characteristics (MacLeod, 1999).

The directed forgetting effect obtained in an item-method paradigm is often explained by selective rehearsal at encoding (e.g., Basden, Basden, & Gargano, 1993). According to this account, maintenance rehearsal refreshes each study word in working memory until the instruction is presented. Following an R instruction, elaborative encoding is engaged to encourage retention; following an F instruction, the word is dropped from the rehearsal set and permitted to decay passively. Because the typical interpretation of the selective rehearsal account fails to describe *how* F words are eliminated from the rehearsal set, one is led to believe that maintenance rehearsal ceases without any further cognitive processes acting upon the to-be-forgotten information. This interpretation essentially purports that successful intentional forgetting occurs due to the passive decay of an unrehearsed memory trace.

Recent evidence has challenged a passive decay interpretation of forgetting by demonstrating that instantiating an F instruction at encoding is even *more* cognitively demanding than instantiating an R instruction (Fawcett & Taylor, 2008). Indeed, following an F instruction participants are slower to detect, localize, or discriminate a secondary visual (e.g., Fawcett & Taylor, 2008) or auditory (Fawcett & Taylor, 2009, December) probe; less likely to make false alarms on probe-absent catch trials (Fawcett & Taylor, 2008); and, because of this slowing on F versus R trials, more likely to successfully prevent an unwanted motor response (Fawcett & Taylor, 2010). Moreover, inhibition of return (IOR) – an effect normally revealed following the removal of visuospatial attention from a peripheral location – is larger following F than R instructions (e.g., Fawcett & Taylor, 2010; Taylor, 2005; Taylor & Fawcett, 2011). These findings are incompatible with the notion that forgetting occurs due to the passive decay of an unrehearsed memory trace and instead suggest that instantiating an F instruction initiates an active

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withdrawal of processing resources from the representation of the F item (including its spatial location in the case of words presented in the periphery; see Taylor, 2005; Fawcett & Taylor, 2010). The purpose of our current investigation is to determine whether this active withdrawal of processing resources is specific to the representation of the F item or whether it has consequences for other task-irrelevant information present in working memory when this withdrawal occurs.

This experiment modified the methods of Fawcett and Taylor (2008) such that probe words requiring a speeded color discrimination response were presented following each study phase memory instruction at stimulus onset asynchronies (SOAs) of 1400 ms, 1800 ms or 2600 ms relative to the memory instruction. Extending Fawcett and Taylor's (2008) findings with detection probes, we expected that RTs to discriminate the color of the probe word would be longer following F than R instructions. Of primary interest, however, was the fate of incidental memory for these probe items on F and R trials.

On the one hand, if an F versus R instruction initiates a differential withdrawal of processing resources from the indicated item only, there should be no direct effect of the memory instruction on incidental memory for a subsequent probe item. Nevertheless, because we predict longer RTs to discriminate the color of this probe item on F than R trials (see Fawcett & Taylor, 2008, 2010), there may be an indirect effect of this potentially increased processing time wherein incidental memory is consequently better for probes on F than R trials. Such a finding would have little theoretical import. On the other hand, it is possible that an active withdrawal of processing resources impacts incidental memory formation for other items represented in working memory after the withdrawal is complete. Worse incidental memory formation for post-F than post-R probe words – despite longer RTs for responding to these items – would be a counter-intuitive finding that would provide converging evidence for an active view of forgetting in an item-method paradigm.

2. Methods

2.1. Participants

Fifty-six undergraduates participated for course credit; participants were run individually in a single session lasting approximately 60 min.[1] All participants reported normal or corrected-to-normal vision and a good understanding of the English language.

2.2. Stimuli and apparatus

This experiment used PsyScope 5.1.2 (Cohen, MacWhinney, Flatt, & Provost, 1993) loaded on an OS9 Macintosh G4-400. Stimuli were presented on a 17″ 1024×768-resolution Macintosh Studio Display color monitor viewed from approximately 57 cm. Probe words were presented against a white background in blue or pink Helvetica size-24 font; all other text were presented in an otherwise identical black font with the exception that a white font (overlaid upon a black rectangle) was used during the recognition phase. R and F memory instructions consisted of two 400-ms tones (high: 1170 Hz, low: 260 Hz) presented via both channels of Sony MDR-XD100 headphones. Responses were recorded from a Macintosh USB keyboard.

A master wordlist of 384 nouns was created using the Paivio, Yuille and Madigan Word List Generator (http://www.math.yorku.ca/SCS/Online/paivio/). Prior to running each participant, the master wordlist was randomly divided into F (n=48), R (n=48), post-F probe (n=48), post-R probe (n=48) and foil (n=192) wordlists, producing unique list compositions for each participant.

2.3. Procedure

Participants received verbal instructions that were reiterated onscreen. These instructions described the task and informed participants that their recognition memory would be tested at the end of the study phase. Although participants were explicitly informed that they would be tested for R words, the instructions did not mention that they would also be tested for F words. Participants were further instructed that they were not even required to read the probe words — only respond to their color (see below).

2.3.1. Practice phase

Five practice trials familiarized participants with the probe color discrimination task. Practice trials were identical to study phase trials except that both study and probe words were replaced by a string of five 'X's.

2.3.2. Familiarization phase

Before the study phase, participants were presented with 8 tone familiarization trials. Each trial presented a visual fixation stimulus ("+") for 1500 ms, followed with equal probability by a high or low tone for 400 ms and a visual reminder of its meaning (e.g., "Remember") for 3000 ms.

2.3.3. Study phase

As depicted in Fig. 1, each study phase trial began with the presentation of a central fixation stimulus ("+") for 1500 ms. After a delay of 800 ms the fixation stimulus was replaced by a word for 600 ms. The word was drawn randomly without replacement from the R or F wordlists. Following the study word by 500 ms, the memory instruction was presented for 400 ms. For half of the participants the high-frequency tone served as the R instruction and the low-frequency tone served as the F instruction; the opposite designations were used for the remaining participants. To replicate the timings used by Fawcett and Taylor (2008), the probe word was presented 1400 ms, 1800 ms or 2600 ms following the onset of the memory instruction and lasted for 600 ms. The period preceding and following the presentation of each probe word was filled with a blank screen. Half of the participants within each tone/memory designation were asked to press the 'z' key to report a blue probe word and the 'm' key to

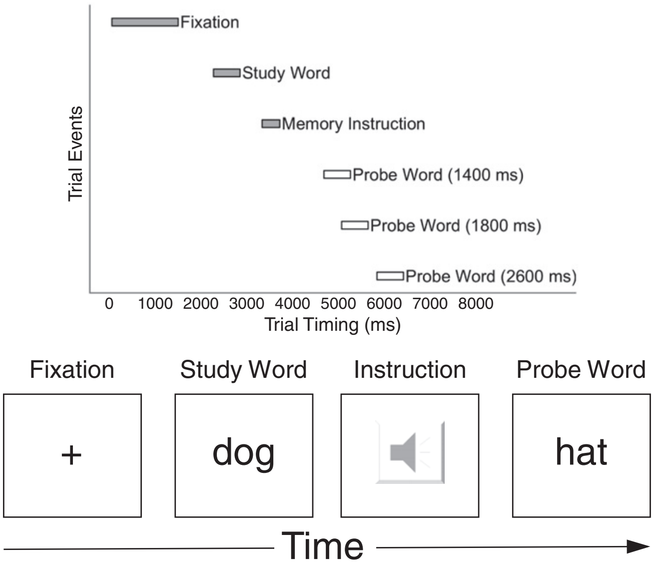

Fig. 1. Methods used in the current experiment. The top panel shows the study phase event timings whereas the bottom panel shows a schematic representation of the study phase trial events.

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[1] This sample was originally conceptualized as two independent replications of the same paradigm containing 32 and 24 participants, respectively. An identical pattern was observed for each analysis and therefore these samples were combined for the sake of exposition.

report a pink word; these key assignments were reversed for the remaining participants.

The duration of all trial events summed to 6600 ms, from the onset of fixation to the offset of the latest (2600 ms SOA) probe; each trial ended with an enforced intertrial interval of 1400 ms raising the total trial duration to 8000 ms. Trial duration remained constant for all trials within this phase regardless of probe word SOA. Overall, 96 study trials were presented, equally distributed across each level of memory instruction, probe color, and SOA. The study phase was both preceded and followed by 6 buffer trials (for a total of 12) to minimize primacy and recency effects. Buffer trials were identical to experimental trials except that no data were gathered or analyzed. Study and probe words presented during buffer trials were the same for all participants, were followed invariably by an R instruction and were not tested for recognition performance.

2.3.4. Recognition phase

During the yes–no recognition task, all of the study and probe words from both R and F trials were randomly intermixed with 192 'new' foil words and presented one at a time. Written instructions informed participants that they should attempt to recognize *all* words that were presented during the previous phase, regardless of whether the item was a study word or one of the colored probe words and regardless of the R or F memory instruction. Participants were required to press the "y" (yes) key on the computer keyboard to confirm that a word had been presented during the study phase (as study or probe word on an R or F trial) and "n" (no) to indicate that it had not. Keyboard input appeared on-screen and could be changed using backspace or submitted using the spacebar. Responses were self-paced.

3. Results

3.1. Study phase data

3.1.1. Color discrimination RTs

Mean RTs were calculated for study phase trials on which a correct discrimination response was made between 100 ms and 2000 ms of probe word onset. Correct RTs were analyzed as a function of the preceding memory instruction (R, F) and instruction-probe word SOA (1400 ms, 1800 ms, 2600 ms) using a repeated-measures analysis of variance (ANOVA). Both the main effect of instruction [$F(1,55) = 8.59$, $MSe = 13182.95$, $p < .01$, $\eta_G^2 = .009$] and SOA [$F(2, 110) = 29.53$, $MSe = 5651.286$, $p < .01$, $\eta_G^2 = .026$] were significant, confirming slower responses following F than R instructions with a tendency for RTs to decrease with increasing SOA (see Fig. 2). Although the instruction × SOA interaction was only marginal [$F(2, 110) = 2.59$, $MSe = 4378.12$, $p = .079$, $\eta_G^2 = .002$], planned contrasts revealed that the predicted F>R RT difference was not significant at the 1400 ms instruction-probe SOA [$F(1, 55) = 0.60$, $MSe = 8716.72$, $p > .44$, $\eta_G^2 = .001$] but was significant at the 1800 ms [$F(1,55) = 10.09$, $MSe = 5762.54$, $p < .01$, $\eta_G^2 = .015$] and 2600 ms [$F(1, 55) = 9.74$, $MSe = 7459.93$, $p < .01$, $\eta_G^2 = .018$] SOAs.

3.1.2. Color discrimination accuracy

An analogous analysis of the percent accuracy (see Fig. 2) revealed only a main effect of instruction [$F(1, 55) = 13.26$, $MSe = 25.56$, $p < .01$, $\eta_G^2 = .01$; all other p's$>.10$] indicating that responses were less accurate during F trials ($M = 92.0\%$, $SE = 0.9\%$) than R trials ($M = 94.0\%$, $SE = 0.9\%$).

3.2. Recognition phase data

3.2.1. Overall analysis

The percentage of "yes" responses was initially analyzed as a function of instruction (R, F), item type (study, probe) and SOA (1400 ms, 1800 ms, 2600 ms) in a three-way repeated-measures analysis of variance (ANOVA). The main effect of instruction was significant, [$F(1, 55) = 82.98$, $MSe = 270.25$, $p < .01$, $\eta_G^2 = .072$], indicating greater performance for R words ($M = 47.6\%$, $SE = 1.9\%$) compared to F words ($M = 36.1\%$, $SE = 2.4\%$) regardless of whether the word had been studied or presented as a probe. The main effect of item type was also significant [$F(1, 55) = 64.22$, $MSe = 857.67$, $p < .01$, $\eta_G^2 = .161$], demonstrating superior performance for study words ($M = 50.9\%$, $SE = 2.3\%$) compared to probe words ($M = 32.8\%$, $SE = 2.4\%$). The instruction × SOA [$F(2, 110) = 3.90$, $MSe = 130.62$, $p < .03$, $\eta_G^2 = .004$] and the instruction × item type [$F(1, 55) = 52.05$, $MSe = 344.24$, $p < .01$, $\eta_G^2 = .059$] interactions were also significant. However, they were qualified by a significant instruction × item type × SOA interaction [$F(2, 110) = 4.87$, $MSe = 123.35$, $p < .01$, $\eta_G^2 = .004$]. Therefore, separate analyses were conducted for the study and probe words exploring the nature of the instruction × SOA interaction. Neither the main effect of SOA [$F(2, 110) = 0.39$, $MSe = 110.50$, $p > .67$, $\eta_G^2 < .001$] nor the SOA × item type [$F(2, 110) = 1.95$, $MSe = 104.61$, $p > .14$, $\eta_G^2 = .001$] reached significance.

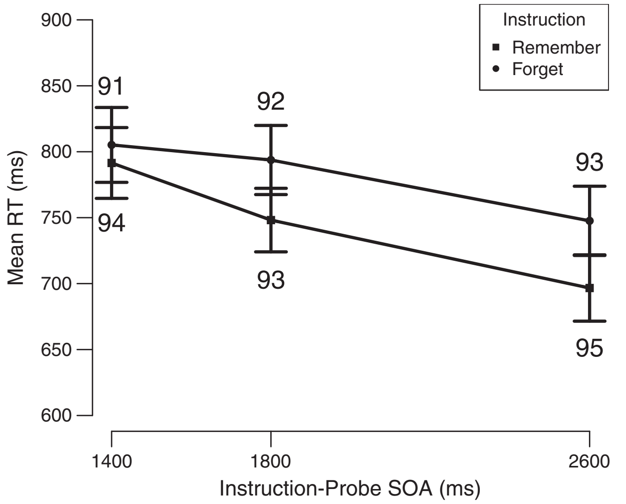

Fig. 2. Study phase: Mean probe color discrimination RTs (ms) and associated percent accuracy as a function of memory instruction (R, F) and post-instruction SOA (1400 ms, 1800 ms, 2600 ms); error bars represent one standard error of the mean.

3.2.2. Study word recognition accuracy

Probe word recognition accuracy was the dependent measure of interest. Nevertheless, study word recognition accuracy was first examined to confirm compliance with the memory instructions. An instruction (R, F) × SOA (1400 ms, 1800 ms, 2600 ms) within-subjects ANOVA was conducted on the percentage of "yes" responses to study words as shown in Fig. 3. The only significant result was the main effect of instruction [$F(1, 55) = 82.84$, $MSe = 485.49$, $p < .01$, $\eta_G^2 = .213$] demonstrating a directed forgetting effect with better recognition of R than F items. Neither the main effect of SOA [$F(2, 110) = 1.03$, $MSe = 102.40$, $p > .36$, $\eta_G^2 = .001$] nor the instruction × SOA interaction [$F(2, 110) = 0.34$, $MSe = 115.78$, $p > .71$, $\eta_G^2 < .001$] even approached significance. Importantly, even the condition in which performance was lowest ($M_{F\text{-}2600} = 38.2\%$, $SE_{F\text{-}2600} = 2.7\%$) was well above the false alarm rate for never-presented foils ($M = 16.0\%$, $SE = 1.8\%$; see Fig. 3).

3.2.3. Probe word recognition accuracy

A comparable instruction (R, F) × SOA (1400 ms, 1800 ms, 2600 ms) within-subjects ANOVA was conducted on the percentage of "yes" responses to probe words as shown in Fig. 4. Only the instruction × SOA interaction was significant [$F(2, 110) = 7.75$, $MSe = 138.19$, $p < .01$, $\eta_G^2 = .015$]; the main effects of instruction [$F(1, 55) = 0.98$, $MSe = 128.99$, $p > .32$, $\eta_G^2 < .001$] and SOA [$F(2, 110) = 1.26$, $MSe = 112.70$, $p > .28$, $\eta_G^2 = .002$] failed to reach significance. Planned

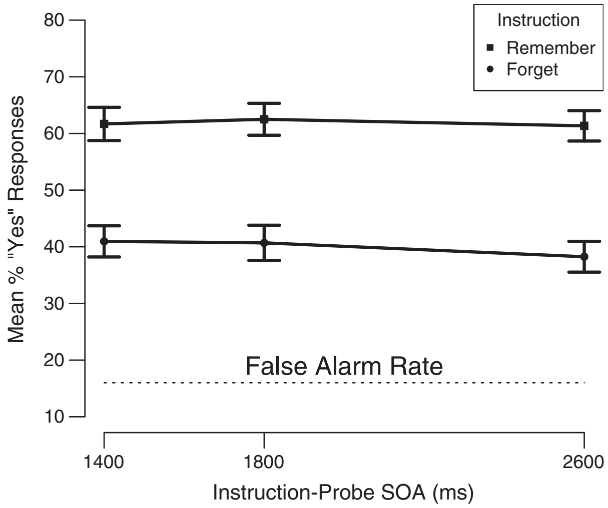

Fig. 3. Recognition phase: Mean percentage of "yes" responses for study words as a function of memory instruction (R, F) and post-instruction SOA (1400 ms, 1800 ms, 2600 ms); error bars represent one standard error of the mean. False alarm rate (percentage of "yes" responses to 'new' foil words) is represented by the dotted line.

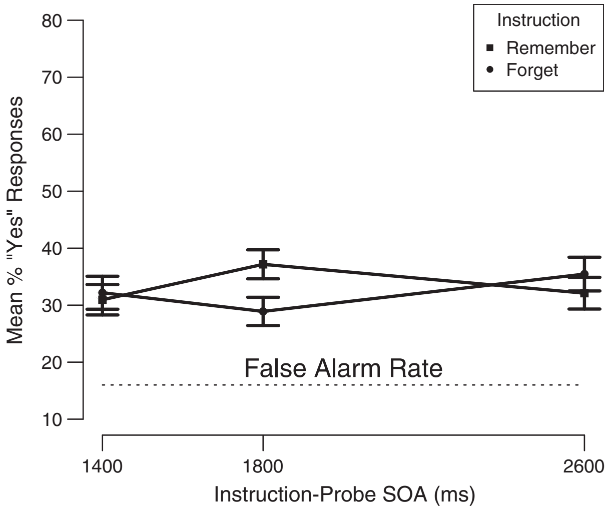

Fig. 4. Recognition phase: Mean percentage of "yes" responses for probe words as a function of memory instruction (R, F) and post-instruction SOA (1400 ms, 1800 ms, 2600 ms); error bars represent one standard error of the mean. False alarm rate (percentage of "yes" responses to 'new' foil words) is represented by the dotted line.

contrasts on the interaction revealed that probe words presented at the 1800 ms instruction-probe SOA were incidentally recognized less frequently following F than R instructions [$F(1, 55) = 16.53$, $MSe = 115.65$, $p < .01$, $\eta^2_G = .047$]; performance following F and R instructions did not differ when the probe word was presented at the 1400 ms [$F(1, 55) = 0.32$, $MSe = 132.88$, $p > .57$, $\eta^2_G < .001$] and 2600 ms SOAs [$F(1, 55) = 2.00$, $MSe = 156.82$, $p > .16$, $\eta^2_G = .006$].[2] Importantly, even at its lowest ($M_{F\text{-}1800} = 28.9\%$, $SE_{F\text{-}1800} = 3.0\%$), probe word recognition was well above the false alarm rate for never-presented foils (16.0%, $SE = 1.8\%$; see Fig. 4).

4. Discussion

Participants were slower to respond to probe words presented 1800 ms or 2600 ms following an F instruction versus an R instruction. These results are broadly consistent with those of Fawcett and Taylor (2008) which showed overall longer detection probe RTs following F than R instructions. Nevertheless, Fawcett and Taylor showed longer RTs for F than R instructions at instruction-probe SOAs of 1400 ms and 1800 ms, whereas the present experiment showed longer RTs for F than R instructions at instruction-probe SOAs of 1800 ms and 2600 ms. This difference in time course function is likely attributable to our use of a discrimination rather than a detection response. Whereas a simple response to report the onset of a probe requires only stimulus detection and motor execution, a choice response to report the color of the probe item requires stimulus detection, stimulus discrimination, response selection, and motor execution, (e.g., Donders, 1868; see Miller & Low, 2001). As a result of the additional processing stages, discrimination responses are typically slower than detection responses. And, when used to assess the development of an underlying cognitive process, the time-course function is typically shifted to the right for discrimination versus detection responses (e.g., Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; for a meta-analytic review, see Samuel & Kat, 2003).

Regardless of the differences between discrimination and detection responses, where probe RTs are used as a proxy measure for cognitive load (see Kahneman, 1973), these results confirm that within at least the first 2600 ms of instruction onset, instantiating an F instruction is more cognitively demanding than instantiating an R instruction (see also Fawcett & Taylor, 2008, 2010). Insofar as the cognitive demands associated with instantiating F versus R instructions is believed to reflect a differential withdrawal of processing resources (e.g., Fawcett & Taylor, 2010; Taylor, 2005; Taylor & Fawcett, 2011), the central question addressed by this study is whether incidental memory formation for other task-irrelevant information represented in working memory (i.e., the identity of the colored probe words) is affected by the purported withdrawal of processing resources following an F instruction. On this, the results of our incidental test of probe word recognition are clear: Incidental memory was worse for probe words that followed F versus R instructions at the 1800 ms SOA. This was true despite longer RTs to discriminate the color of post-F versus post-R probe words presented at this interval. The current investigation provides converging evidence for a cognitively demanding withdrawal of attention following an F instruction by demonstrating a brief temporal window during which the efficiency of ignoring irrelevant information (in this case, the identity of the colored probe word) is heightened in working memory.[3] We presume that this increased efficiency for ignoring the identity of the probe word is due to the relative unavailability of processing resources due to the withdrawal of attention following an F instruction but also discuss the possibility that it may be due to relatively improved executive control following an F instruction.

The time-course of our RT and incidental memory effects suggest that the withdrawal of processing resources initiated by the F instruction takes time to complete. RTs to discriminate the color of the probe words were slower post-F than post-R at both the 1800 ms and 2600 ms intervals; the effect of memory instruction on incidental memory formation for the probe words was observable at only the 1800 ms post-instruction SOA. This dissociation in the time-course function for color discrimination and incidental memory formation suggests that the withdrawal of processing resources that leads to poor incidental memory formation for the probe items contributes to the longer post-F than post-R RTs but is not solely responsible for this RT difference. If it were, RTs would be longer post-F than post-R at only the 1800 ms interval at which effects on incidental memory were also observed. It is not clear what additional processes might contribute to longer post-F

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[2] The pattern of incidental probe word recognition reported in this and the following analysis was unaffected by the exclusion of probe words for which the study phase color discrimination response was incorrect; this suggests that participants demonstrated worse performance for probe words following F than R instructions despite having processed these words (to correctly discriminate their color).

[3] We would like to thank an anonymous reviewer for suggesting this interpretation.

than post-R probe RTs but it is conceivable that they include study-phase retrieval and cumulative rehearsal of R items from previous trials (e.g., Sahakyan & Foster, 2009; see Greene, 1989). To be clear, we are not suggesting that study-phase retrieval and cumulative rehearsal is primarily responsible for the longer post-F than post-R probe RTs; indeed, collapsing data across studies in our lab reveal that longer probe RTs are observed following F compared to R instructions even when the analysis is restricted to the first study trial such that there are no preceding study items to cumulatively rehearse (Fawcett et al., 2011). Instead, we are suggesting that the withdrawal of processing resources from items in working memory that have been deemed irrelevant by virtue of the F instruction might free limited capacity resources to foster the retrieval and selective rehearsal of R items later in the trial. Under this view, forgetting is an active cognitive process that operates in the short term to foster the long-term rehearsal and commitment of R items to memory. In this way, the time-course of longer post-F than post-R probe RTs may reflect the operation of two mechanisms, each of which is cognitively demanding: First, an active withdrawal of processing resources initiated by the F instruction that can limit incidental memory formation for items that enter working memory subsequent to this withdrawal; second, retrieval and selective rehearsal of previous R items.

To determine whether the active withdrawal of processing resources following an F instruction is related to the success of instantiating the intention to forget, we examined the relationship between the *intentional forgetting* of study words and the *incidental forgetting* of probe words on F trials. To determine whether any relationship between memory intention and incidental memory formation is specific to F trials, we also explored the relationship between the *intentional remembering* of study words and the *incidental remembering* of probe words on R trials. We analyzed probe word recognition using a linear mixed-effects regression model (see Bates, 2007) with subject and word as random effects and with memory instruction, the second degree polynomial of SOA, and whether the study word presented in that trial was subsequently recognized, as fixed effects. If the decrement in incidental memory formation were associated with whatever cognitive mechanisms are engaged to intentionally forget the study word, incidental recognition should be lower for F trials on which the study word was successfully forgotten relative to F trials on which the study word was remembered. Alternately, if this difference resulted from an increase in incidental memory on R trials, for example due to additional relational processing afforded to the probe word (e.g., by associating the probe and study words) recognition should be higher for R trials on which the study word was successfully remembered relative to R trials on which the study word was unintentionally forgotten. In this analysis, the main effect of instruction [$Z = 3.62$, $p < .01$] and the interaction between instruction and the second order polynomial of SOA was significant [$Z = -3.79$, $p < .01$] supporting the observation that probe word performance following an F instruction was lowest at the 1800 ms interval whereas probe word performance following an R instruction was highest at the 1800 ms interval. The only other term to reach significance was the study word recognition × instruction interaction [$Z = -2.59$, $p < .01$]. As predicted, participants were less likely to recognize probe words following F words that were later forgotten ($M_{\text{F-forgotten}} = 30\%$, $SE_{\text{F-forgotten}} = 2\%$) than those that were later remembered ($M_{\text{F-remembered}} = 35\%$, $SE_{\text{F-remembered}} = 3\%$). There was no such tendency for R trials, where probe word recognition was equivalent regardless of whether the preceding study word had been remembered ($M_{\text{R-remembered}} = 33\%$, $SE_{\text{R-remembered}} = 3\%$) or forgotten ($M_{\text{R-forgotten}} = 33\%$, $SE_{\text{R-forgotten}} = 2\%$).

Our findings demonstrate that the successful instantiation of an F instruction had consequences not only for the F item itself (i.e., leading to a directed forgetting effect in recognition), but also for the availability of processing resources for a subsequent probe word (i.e., limiting incidental memory formation for these items). What is not clear is whether the probe words would have been similarly affected had they been actively encoded. In our study, the identity of any given probe item was task-irrelevant with respect to the speeded color discrimination; participants did not believe they would ever be tested for the probe word identities nor were they even asked to read the probe words. The fact that there was *any* incidental memory formation for these probe words likely reflects, in large measure, the automaticity of word reading during color discrimination (e.g., Stroop, 1935). Because probe word identity was task-irrelevant at study (with respect to the speeded color discrimination) and processing this identity likely occurred automatically in spite of this task-irrelevance, we are left with the question of whether the effect of the F instruction on incidental memory formation for these items was due to their task-irrelevance per se. In other words, it is possible that the F instruction initiates a withdrawal of processing resources only from *irrelevant* information in working memory; had probe word identity been task-relevant, it is possible that incidental memory formation might not have been similarly impacted by a preceding F instruction. We are currently testing this possibility. Should it prove to be the case that the F instruction initiates a withdrawal of processing resources only from irrelevant items in working memory, this withdrawal could serve the function of clearing working memory of outdated information analogous to garbage collection procedures in certain computer programming languages.

Regardless of whether the effect of the F instruction is limited to irrelevant information or extends to relevant information presented at some interval following the F instruction, the fact that an F instruction engages a cognitive mechanism that limits incidental memory formation for subsequent items raises an important question: What is the *function* of such a mechanism? One possibility is that withdrawing attention following the F instruction *causes* forgetting (e.g., Zacks, Radvansky, & Hasher, 1996). In this case, the presentation of an F instruction leads to a withdrawal of attention that functionally clears the working memory buffer (either of all items or only of task-irrelevant items). This would include the F item as well as the subsequent post-instruction probe item. This characterization, however, could be interpreted as incongruent with our time-course data which shows no decrement in incidental memory formation for probes that follow the F instruction at a 1400 ms interval but a decrement for those that follow at 1800 ms. It is difficult to imagine how a single mechanism could effectively clear the working memory buffer of the F item as well as an item presented 1800 ms later, but not an item presented during the intervening 1400 ms interval. The withdrawal of processing resources appears to be more effective on trials on which the F instruction is successfully instantiated (hence the relationship between intentional versus unintentional forgetting and the decrement in incidental memory formation), but this does not necessarily imply that this withdrawal is responsible for successful intentional forgetting. Instead, it may be that the withdrawal of attentional resources and ejection of subsequent items from working memory occur as a *consequence* of successful intentional forgetting (see Taylor & Fawcett, 2011). For example, enacting an F instruction might initiate or require a change in mental context (e.g., Sahakyan & Foster, 2009) and/or a shift of attention away from the internal representation of a now-irrelevant F item (Wylie, Foxe, & Taylor, 2008). In this case, the purpose of attentional withdrawal might not be to forget per se but rather to clear the working memory buffer of current thoughts as a means of changing mindset or attentional focus; this would enable the selective rehearsal of R items that is ultimately responsible for the directed forgetting effect.

4.1. The role of rehearsal

In analyzing our results, we have presumed that the longer post-F than post-R RTs are due to the cognitively demanding withdrawal of attentional resources (Taylor, 2005; see also, Fawcett & Taylor, 2008, 2010; Taylor & Fawcett, 2011) and that this withdrawal is responsible for relatively impaired incidental memory formation for probe items that are presented following F instructions. In interpreting our probe RT data, an alternative explanation worth addressing is the possibility that the post-F versus post-R RT difference is due primarily to study-phase retrieval and cumulative rehearsal of R items on F trials (Greene, 1989; Sahakyan & Foster, 2009). Such an account argues that following an F instruction participants *effortlessly* discard the F word to instead engage in the effortful retrieval and rehearsal of prior R words. In this instance rehearsal is defined as any form of additional processing (verbal rehearsal, visualization, etc.; e.g., Hourihan, Ozubko, & MacLeod, 2009) afforded the R item following its retrieval on an F trial. The effortful retrieval of prior R words would slow probe discrimination responses following F instructions and distract participants from the probe word on those trials thereby leading to reduced incidental memory formation. While superficially consistent with the present results, this hypothesis can account for our findings *only* if it assumes that such retrieval takes place on F trials only; there can be no allowance for similar study-phase retrieval and cumulative rehearsal of previous R items on R trials. Without this allowance, the hypothesis predicts that F and R trials would be equivalently demanding and that RTs to discriminate the probe color should likewise be equivalent. However, we know post-instruction probe RTs to be longer following F than R trials across a range of SOAs (Fawcett & Taylor, 2008; see also Taylor & Fawcett, 2011). Thus, the only way this hypothesis can account for our data is if we presume that study-phase retrieval and cumulative rehearsal of previous R words occurs only on F trials. This seems a tenuous assumption at best. Based on this and other arguments, Fawcett and Taylor (2008, pg. 1177) (see also, Fawcett and Taylor, 2010) rejected this study-phase retrieval and cumulative rehearsal strategy as an inadequate account of the robust finding of longer post-F than post-R probe RTs; they also included experimental controls designed to discourage the use of such a strategy and to minimize the impact of such a strategy on the probe RT data. Moreover, as noted above, longer post-F than post-R probe RTs occur even when only the first trial is analyzed and there are no previous R items to retrieve and rehearse (Fawcett et al., 2011). Unfortunately, our inclusion of buffer trials – while a necessary control for primacy effects in memory – preclude a first-trial analysis of the present data.

4.2. Future directions

The observation that item-method memory instructions impact incidental memory formation raises many questions. For example, although we can conclude from the current data that an F instruction interferes with the incidental retention of unrelated task-irrelevant probe words it remains to be seen whether task-relevant information would be insulated from this effect. We would argue that this should be the case — it would be detrimental to cognitive efficiency if we were to lose *all* of the information stored in the working memory buffer for want of removing a single *piece* of information. It is much more sensible to imagine a mechanism intended to remove only those details unlikely to be of immediate use. Perhaps an even more useful mechanism would remove information from working memory based upon its semantic or perceptual similarities to the now-irrelevant F item. The current experiments are unable to address this possibility because the probe words were unrelated to the study word. The relationship between the properties of the study word and the probability of the probe word being affected by the withdrawal of processing resources remains an open question that is beyond the scope of this short report.

Our findings also re-open the door for the exploration of so-called inhibitory processes in item-method directed forgetting. We should be clear that we make no presumptions regarding any protracted suppression of the F word in our current framework. Instead we have maintained that an F instruction results in the withdrawal of processing resources from the study word in working memory: We have no reason to believe that the semantic representation of that word suffers any long-lasting effects (see Marks & Dulaney, 2001) as might have been predicted in the past (see Zacks et al., 1996). Nevertheless, proponents of an inhibitory account might argue that an F instruction does not impair subsequent incidental memory formation due to the relative unavailability of withdrawn processing resources but because the F instruction facilitates the subsequent engagement of so-called inhibitory mechanisms. Under this view, reduced incidental memory formation for probe items would be interpreted as improved inhibitory control following an F versus an R instruction. This improved inhibitory control would limit the processing of the probe word identity during performance of the color discrimination task and thereby limit incidental memory formation. Although we are not aware of any strong evidence that compels the view that instantiating an F instruction requires inhibition to remove the F item from the rehearsal set, it is certainly conceivable that the successful instantiation of an F instruction may impact subsequent processes that require executive control mechanisms (inhibitory or not). This possibility warrants consideration, especially in light of the fact that the successful instantiation of an F instruction activates the same frontal areas as are activated by an instruction to withhold a prepotent motor response as given in a stop-signal task (Wylie et al., 2008). Even though the relationship between item-method directed forgetting and stop signal inhibition is likely based on analogy (Hourihan & Taylor, 2006) rather than identity (see Fawcett & Taylor, 2010), it does suggest that the after-effects of an F instruction could be limited to other tasks that likewise depend on executive control mechanisms.

5. Conclusion

We suggest that instantiating an F instruction initiates a withdrawal of processing resources from the episodic representation of the F item within the working memory buffer (including its task-irrelevant spatial representation, see Taylor, 2005; Fawcett & Taylor, 2010; Hourihan, Goldberg & Taylor, 2007). Incidental memory formation is relatively impaired for other irrelevant information that enters the working memory buffer following this removal of processing resources. We have demonstrated that the effects of this withdrawal of processing resources are time-limited and associated with successful instantiation of the intention to forget. It remains to be seen whether this mechanism is a *cause* or a *consequence* of successful intentional forgetting, although we currently favor the latter interpretation (see Taylor & Fawcett, 2011).

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