DUAL PROCESSES IN RECOGNITION MEMORY

DUAL PROCESSES IN RECOGNITION MEMORY: THE OPPOSING INFLUENCES OF PROCESSING-EASE ON RECOGNITION MEMORY DECISIONS.

By

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Abstract

A key finding in recognition memory experiments is that difficult-to-process stimuli are often remembered better than easy-to-process stimuli. In the present study, processing difficulty was manipulated by presenting participants with interleaved word pairs which were either congruent (perceptually fluent) or incongruent (perceptually disfluent). In a reanalysis of data sets from several prior studies, we found that recognition sensitivity (d') was greater for incongruent items. However, this benefit in d' for incongruent items was not reflected in the hit rates for responses in the two slowest response time quartiles; here we found equivalent hit rates for congruent and incongruent items. We propose that a dual process account can explain this pattern of equivalent hit rates. While there is one process at study which leads to better memory for incongruent items, there is another process at test that affects bias rather than sensitivity. Specifically, items at test which were perceptually fluent lead to an illusion of memory, where participants mistook the ease of processing these items with prior experience. In a following empirical study, by manipulating processing fluency at study separately from processing fluency at test, we investigated the contribution of each of these processes to recognition memory decisions. The results offered strong evidence for this dual-process account.

Acknowledgements

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Introduction

Interacting with an uncertain world around us requires flexibility in cognitive processing. Cognitive conflicts can determine how we allocate our attentional resources, and as we navigate the world around us some interactions with our environment will require an increase in attention to ensure that behaviour aligns with task goals. These flexible changes in attentional processing are a hallmark of cognitive control, a feature of our cognitive system that allows for adaptability in the way we perform tasks.

Botvinick et al. (2001) proposed that processing conflict signals a need for such adaptive changes in attention. In their conflict monitoring framework, cognitive conflict is defined as coactivation of competing responses under the constraint of a given task set. For example, imagine a situation in which a green traffic light signals us to drive whereas a pedestrian in the middle of the same intersection signals us to brake. In this case, the conflict between these two actions would ramp up cognitive control, ensuring that the action of braking takes precedence over driving (see also Egner and Hirsch, 2005).

The effects of conflict on cognitive control have been studied extensively in the laboratory using a variety of selective attention tasks (Eriksen & Eriksen, 1974; Gratton et al., 1992). For example, in the flanker task, responses to targets flanked by incongruent distractors are slower than responses to targets flanked by congruent distractors. Importantly, this relative slowing in response time to incongruent trials depends on the preceding trial type, with smaller congruency effects following incongruent trials than following congruent trials (Gratton, 1992). These sequential congruency effects are thought to reflect flexible adaptations to conflict—incongruent trials produce conflict that results in an adaptation which reduces conflict on the following trial. Other researchers have investigated this form of conflict adaptation using the

Stroop colour-naming task. A smaller Stroop congruency effect is typically observed following incongruent trials than following congruent trials (Kerns et al., 2004)

Selective attention conflict and remembering

The present study focuses on the effect of cognitive conflict on longer-term learning and memory. It is well known that remembering is profoundly impacted by dividing attention during encoding (Craik et al., 1996; Jacoby, Woloshyn & Kelley, 1989). In light of this strong link between memory and attention, it is surprising that little research has focused on links between adaptations of attention in selective attention contexts and remembering. However, a small number of recent studies have begun to focus on this issue.

The method used to study conflict effects on memory of most relevance to the present study was introduced by Rosner et al. (2015). In a study phase, participants were presented with pairs of interleaved red and green words, as displayed in Figure 1. For congruent items the identity of the two words was the same, whereas for incongruent items the identity of the two words was different. The study phase task was to read aloud the red word and ignore the green word as quickly and accurately as possible. In a following surprise recognition test, these same items were randomly intermixed with congruent and incongruent new items, and participants were to indicate whether the red target word in each test item was old or new. The key result was that recognition sensitivity was greater for incongruent items. However, a particular pattern of hit and false alarm rates was also notable. Though not statistically significant in every experiment, hit rates tended to be higher for incongruent than congruent items, and false alarm rates tended to be lower for incongruent items than congruent items. An example of this pattern of hits and false alarms is displayed in the left panel of Figure 2. This pattern of results is known as a mirror effect, and it has been observed for many properties of items that produce different levels of recognition sensitivity, such as word frequency, concreteness, and meaningfulness (Glanzer & Adams, 1985).

Figure 1. Depiction of stimuli used in Rosner et al. (2015) and all experiments of the re-analysis. The item on the left is an incongruent item, where the two interleaved words are different. On the right is a congruent item, where the two interleaved words are the same. The location of the words was counterbalanced within each item-type, so that the red target word appeared in the top position for half of the trials and the bottom position for the other half of trials.

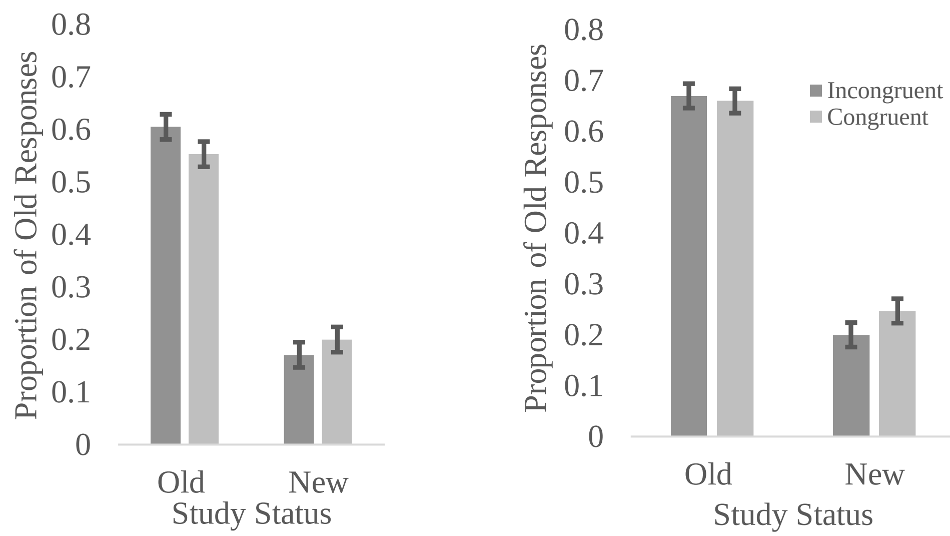

Figure 2. Mean proportion "old" responses to old and new items as a function of trial type. Recognition sensitivity is greater for incongruent items in both cases. Left is an example of a recognition memory mirror effect as seen in Rosner et al. (2015) Experiment 1. Right depicts a sensitivity difference with equivalent hit rates, as observed by Davis et al. (2020).

Krebs et al. (2015) also reported a finding that linked selective attention conflict and remembering, with better recognition sensitivity for items that were difficult to encode. In their study, participants completed a face-word Stroop task in which they were presented with male or female faces overlaid with the word "man", "woman" or "house". These stimuli were defined as congruent (i.e., a face overlaid with its corresponding gender), incongruent (i.e., a face overlaid with the opposite gender) or neutral (i.e., a face overlaid with "house"). Participants were to decide whether each face in this phase of the experiment was male or female. An incidental recognition memory task followed in which they indicated whether or not faces were seen in the previous phase of the experiment. Faces from incongruent items during the first phase of the experiment were recognized better than faces from congruent items. Incongruent items also produced greater activation in brain areas known to be involved in cognitive control during the face-word Stroop task (Krebs et al., 2015). The authors proposed that conflict on incongruent trials increased attention to the target stimulus, which led to deeper encoding for these items (Egner & Hirsch, 2005).

A link between conflict during encoding and later memory was also reported by Muhmenthaler and Meier (2019). They examined the effects of both task switching and response-category conflict on subsequent memory. Participants were presented with congruent items (two identical interleaved words) and incongruent items (two different interleaved words) in a study phase that required them to switch between two semantic categorisation tasks in a predictable order. Following the categorization task, a surprise memory task required participants to recall targets from the prior categorization phase. The results did show better memory for incongruent targets than congruent targets under some conditions. In particular, only when cognitive conflict directed attention to targets was a memory benefit for incongruent items observed; in all other cases, recall for congruent and incongruent items did not differ.

A study by Ptok et al. (2019) focused on a distinction between the effect of two types of conflict on later memory. Whereas response conflict tended not to produce superior recognition for incongruent items, semantic conflict did consistently produce superior recognition for incongruent items. In particular, in a semantic priming task participants were asked to classify nouns as alive or inanimate. These target stimuli were presented alongside primes that were either congruent (i.e., the word “animal” alongside an animate concrete noun) or incongruent (i.e., the word “thing” alongside an animate concrete noun). In a following recognition task, there was a strong congruency effect, with better memory performance for incongruently primed stimuli.

Failures to observe conflict-related memory enhancement

Although the above studies did report conflict-related memory enhancements, several studies have failed to find such effects. Ortiz-Tudela et al. (2018) investigated the effect of expectation violation on recognition memory. In a study phase, participants were presented with a validity paradigm where each trial featured an anticipatory visual cue followed by a target. The visual cue indicated where the ensuing target was likely to appear; this target could then appear either at the expected location (valid trials) or at the opposite location (invalid trials). Following a brief distractor phase, participants completed a surprise recognition test phase. Across seven experiments, they failed to find a memory benefit for expectation-violating invalid trials.

Jimenez et al. (2020) also reported a failure to replicate the study of Krebs et al. (2015). They used a face-word Stroop task adapted from Krebs et al. (2015) in a study phase, and following a 15-minute distractor task participants completed a surprise recognition memory test. In contrast with Krebs et al.'s (2015) result, there was no significant difference between memory performance for incongruent and congruent stimuli. And as noted above, Muhmenthaler and Meier (2019) and Ptok et al. (2019) did observe conflict-driven enhancements in memory in some conditions and tasks but not in others.

Building on these concerns, Jimenez et al. pointed to a property of the result reported by Rosner et al. (2015) that merits further scrutiny. Davis et al. (2020) replicated Rosner et al.'s finding of higher recognition sensitivity for incongruent items than congruent items. However, the hit rate portion of the mirror effect was not observed (see right panel of Figure 2);

participants were equally likely to judge old congruent and old incongruent items to be old. This result led Jimenez et al. to question whether the congruency effect measured with this method could be related entirely to how participants respond to new items, and not related at all to memory for old items. If this concern were justified, it would undermine the proposal that incongruency results in an attention adaptation that benefits recognition memory.

Though recognition sensitivity formally requires a comparison of both the hit rates and false alarm rates, the absence of a hit rate difference can lead researchers to look for alternative accounts for putative sensitivity effects. For example, in the case of the study of Davis et al. (2020), it was suggested that the apparent sensitivity difference between congruent and incongruent items could instead have been produced by an idiosyncratic false alarm effect that has nothing to do with recognition sensitivity—participants may simply tend to judge new congruent items to be old in the test phase because they are easier to process. As described below, and acknowledged by Davis et al., there are good reasons to believe that perceptual fluency indeed contributes to the false alarm rates in this recognition method.

The idea that recognition memory judgements can be based on perceptual fluency is well supported (Jacoby & Dallas, 1981). Further, processing fluency for new items in a recognition test phase can indeed raise false alarm rates, producing an illusion of memory (Jacoby & Whitehouse, 1989). In a seminal study of this issue, Jacoby and Whitehouse (1989) presented a list of words in a study phase and participants were instructed to read the words silently. At test, each word was preceded by a context word that either matched or mismatched the test word. For some participants, this context word was presented briefly enough to preclude awareness by the participant. These participants were more likely to falsely identify a new test word as old when the context and test word matched than when the context and test word mismatched. This result is consistent with a fluency attribution account, according to which fluent processing caused by the match between the context and test words is misattributed to past experience (Jacoby & Dallas, 1981).

In light of this well-established finding, it seems possible that ease of processing for congruent test items in the method of Rosner et al. (2015) is indeed attributed to prior experience and does increase false alarm rates. However, it seems likely that this misattribution would occur not only for congruent new items, but also for congruent old items; that is, congruency at test should impact both hit rates and false alarm rates. If indeed congruency is misattributed to prior experience for old items, then the absence of a hit rate difference for congruent and incongruent items is a puzzle that seems best solved by positing two opposing influences on hit rates: (1) congruent items are more weakly encoded than incongruent items, which decreases hit rates; and (2) congruent items are subject to greater processing fluency at test than incongruent items, which increases hit rates. By this view, one process operating at study and another process operating at test co-determine the hit-rate pattern observed.

The present study

To address this issue in the present study, we took two different approaches. First, we pulled together multiple data sets from prior studies and conducted a re-analysis of the results that included speed of recognition response as a factor. The rationale for this re-analysis is that it offered an opportunity to evaluate whether the putative two processes that contribute to hit rates followed different time courses. Second, we conducted a new empirical study that separately manipulated congruency at study and congruency at test. Prior studies that used items that were congruent both at study and at test made it difficult to observe the separate contributions of the putative two processes that contribute to hit rates. In summary, our dual process account proposed above explicitly predicts opposing influences on hit rates of congruency at study and congruency at test. The method used in the present empirical study allowed us to directly examine these opposing influences.

Study 1: A re-analysis of congruency effects on recognition memory

Speed of response has been used to infer the processes underlying memory decisions (Boldini et al., 2004; Jacoby, 1991; Yonelinas, 2002). To tease apart the putative two processes underlying recognition memory in the Rosner et al. (2015) method, we took this same approach by re-analysing recognition performance from several data sets with speed of recognition response included as a factor. We hypothesised that these two processes might play out over different time courses.

Retrieval is the first of our two processes and it can occur through either recollection or familiarity. Recollection is thought to be a slow and analytic process while familiarity is a fast, automatic process. This is especially true for basic recognition tasks which only require participants to indicate whether an item is “OLD” or “NEW” (Atkinson & Juola, 1973; Yonelinas, 2002). Boldini et al. (2004) used this principle to demonstrate a dissociation between the effect of study-test modality match and levels-of-processing. They imposed varying response deadlines on participants during the recognition test. At short response deadlines, recognition sensitivity was greater when study-test modality matched compared to when they mismatched and there was no effect of level of processing. In contrast, at long response deadlines, a levels of processing effect occurred with greater recognition sensitivity for deeply processed words than words processed at a shallow level. Under the assumption that study-test modality match influenced familiarity, and level of processing influenced recollection, this study offers compelling evidence that recognition can be based on a rapid familiarity process and a slow recollection process.

However, when a recognition task requires additional processing, the opposite pattern can be observed (Rotello & Zeng, 2008). The remember-know paradigm (Tulving, 1985) asks participants to report whether they remember specific details about old items or know that they studied it before despite a lack of conscious recollection. This paradigm aims to distinguish the relative contributions of recollection (i.e., measured with remember responses) and familiarity (i.e., derived from know responses) to participants' retrieval. An assessment of participant response times across several studies indicates that remember judgements are faster than know judgments (Dewhurst & Conway, 1994; Rotello & Zeng, 2008; Diana et al., 2006). This task manipulation appears to invite participants to first search their memory and make a remember response if recollected information is available. When no recollected information is available, but the item is familiar, participants make a know response (Diana et al., 2006).

We propose that our second fluency-based bias process comes into play once retrieval fails and hence is a slower process than retrieval (Brainerd et al., 2019). In the absence of successful retrieval, participants use perceptual fluency as a heuristic when making recognition memory decisions. Items that are fluently processed are likely to be judged as old (Jacoby & Dallas, 1981).

Following the notion that our two processes operate over different time courses, we divided participant recognition responses into response time quartiles. We aimed to examine whether recognition performance could reveal the relative contributions of these two processes to recognition memory decisions. Our predictions with respect to hit rates were as follows. In quartiles where successful retrieval is the dominant process, we should see a clear difference in hit rates, with higher hit rates for incongruent items than congruent items. Overall recognition sensitivity should be greater in these quartiles. In contrast, in quartiles where fluency-based attributions of familiarity are the dominant process, we should not see a hit rate difference between incongruent and congruent items. This prediction is based on the idea that fluency-based attributions of familiarity be higher for congruent than incongruent items, which opposes the influence that produces higher hit rates for incongruent items. Overall recognition sensitivity should be poor in these quartiles.

Methods

Participants

Data from this reanalysis were drawn from Experiments 1 and 2a reported by Rosner et al. (2015), from both the blocked and mixed groups of Experiment 2B reported by Davis et al. (2020), and from a previously unpublished set of data. In total, 120 participants from the McMaster University research participant pool completed these experiments, with 24 participants in each of the five data sets. All participants had normal or corrected-to-normal vision, spoke English fluently, and completed the experiment in exchange for course credit.

Apparatus and Stimuli

All experiments were run on a Dell computer using either Presentation experimental software (v.16.3, http://www.neurobs.com) or Psychopy experimental software (Peirce, 2007, 2009). Participants sat approximately 50 cm from the monitor and were tested individually. The stimuli were identical to those used by Rosner et al. (2015) and are depicted in Figure 1. All stimuli consisted of two interleaved words presented in the middle of the screen against a black background. For incongruent items the two interleaved words had different identities, whereas for congruent items the two interleaved words had the same identity. The red target word was presented randomly either above or below the green distractor word. In the test phase, old items were presented exactly as they appeared in the study phase; that is, red target words appeared with the same green distractor words as at study, and in the same position (above/below) relative to the green distractor words as at study. The experiments used 360 five-letter words that were all high frequency nouns (Kucˇera & Francis, 1967).

Procedure

The procedures of the five experiments re-analyzed here were all highly similar. In all cases, congruent and incongruent items were presented in the study phase, and then recognition memory was tested shortly after with congruent or incongruent items that were old or new. In the test phase, in all cases old items were target-distractor pairs that were identical to those studied, whereas new items were target-distractor pairs in which both target and distractor were new. In the study phase(s) the task was simply to read aloud the red target word. In the test phase(s), the task was to indicate whether the red target word was old or new; for all old responses a remember/know discrimination was then made (Tulving, 1985). For three of the data sets, there was a single study phase with 120 items, and a single test phase with 240 items (Experiments 1 and 2a of Rosner et al. (2015) and the unpublished data set). Congruent and incongruent items were randomly intermixed in both the study and test phases for these three data sets. For the remaining two data sets, there were two study phases with 60 words each, and two test phases with 120 words that followed each of the study phases (the blocked and mixed groups of Experiment 2b of Davis et al., 2020). For one of these data sets, recognition of congruent and incongruent items was tested separately in each of the two study-test cycles, whereas for the other data set, congruent and incongruent items were randomly intermixed in both study-test cycles. Between the study and test phases there was a short distractor phase in which participants completed simple arithmetic problems. The duration of the distractor phase was either ten minutes (Experiments 1 and 2a of Rosner et al. 2015, and the unpublished experiment), or four minutes (Experiment 2b of Davis et al., 2020).

For each trial in the study phases, a central fixation cross was presented for 2,000 ms, followed by a study item (a congruent or incongruent word pair) presented for 1,000 ms. Response times (RTs) were recorded from the onset of the study item to the onset of a vocal response, as detected by a microphone placed in front of the participant. Following offset of the study item, a blank screen was presented until the experimenter coded the participants' response. Responses were coded by the experiment as correct, incorrect, or spoil by pressing "1", "2", or "3", respectively, on a computer keyboard. Incorrect responses occurred when participants named aloud a word other than the target word. Responses were coded as a spoil if a spurious noise was suspected to have set off the microphone before the response was made (e.g., coughing or stuttering before responding).

Following a short distractor phase, detailed instructions for the test phase were then provided, both on screen and verbally. Each trial in the test phase began with a central fixation cross presented for 2,000 ms, after which a test item (a congruent or incongruent word pair) appeared on screen with the words "OLD" and "NEW" presented just below and to the left or right, respectively. The test item remained on screen until participants responded with a key press whether the target red word was old ("A" or "left" key) or new ("L" or "right" key). Participants were told to ignore the green distractors and make a recognition decision only for the red target word. When participants made an "old" response, the test item stayed on screen and the words "OLD" and "NEW" were replaced by "TYPE A" and "TYPE B", respectively. The remember/know instructions given at the outset of the test phase asked participants to designate a feeling of "remembering" as a TYPE A memory, and a feeling of "knowing" as a TYPE B memory (see Rajaram, 1993; McCabe & Geraci, 2009). Participants recorded those remember/know decisions by pressing the "A" key for remember or the "L" key for know.

Design

All of the items in the experiments were constructed using a set of 360 five-letter high frequency words. In all experiments items were counterbalanced across conditions such that each word served equally often as an old congruent target, old incongruent target, old incongruent distractor, new congruent target, new incongruent target, and new incongruent distractor (for specific details of counterbalancing, see Rosner et al., 2015). The key dependent variable in all experiments was the proportion of items judged old, and the key independent variables in all experiments were congruency (congruent/incongruent) and study status (old/new).

Results

Word naming times from the study phase for correctly named incongruent and congruent targets were submitted to a mixed factor ANOVA that treated experiment (1-5) as a between-subjects variable and congruency (congruent/incongruent) as a within-subject variable. This analysis revealed a main effect of congruency, $F(1,115) = 154.23$, $p < .001$, $\eta_{p^2} = 0.57$. Mean naming times were slower for incongruent items (686 ms) than for congruent items (608 ms) items.

Signal Detection Analyses

We first adopted a signal detection approach to analyzing the recognition data. To examine recognition sensitivity, we computed d' values. To examine response bias, we computed *c*, the distance to the participant's response criterion from the midpoint between signal and noise distributions. A positive value of c reflects a tendency to be conservative (i.e., to respond "new"), whereas a negative value of c reflects a tendency to be liberal (i.e., to say "old"). These d' and c values were computed for each combination of the congruency (congruent/incongruent) and quartile (1-4) variables, for each experiment (1-5), and then submitted to mixed factor ANOVAs that treated congruency and quartile as within-subject variables, and experiment as a between-subjects variable. Mean d’ values for each congruency and quartile, collapsed across experiment, are displayed in Figure 3, while corresponding c values are displayed in Figure 4.

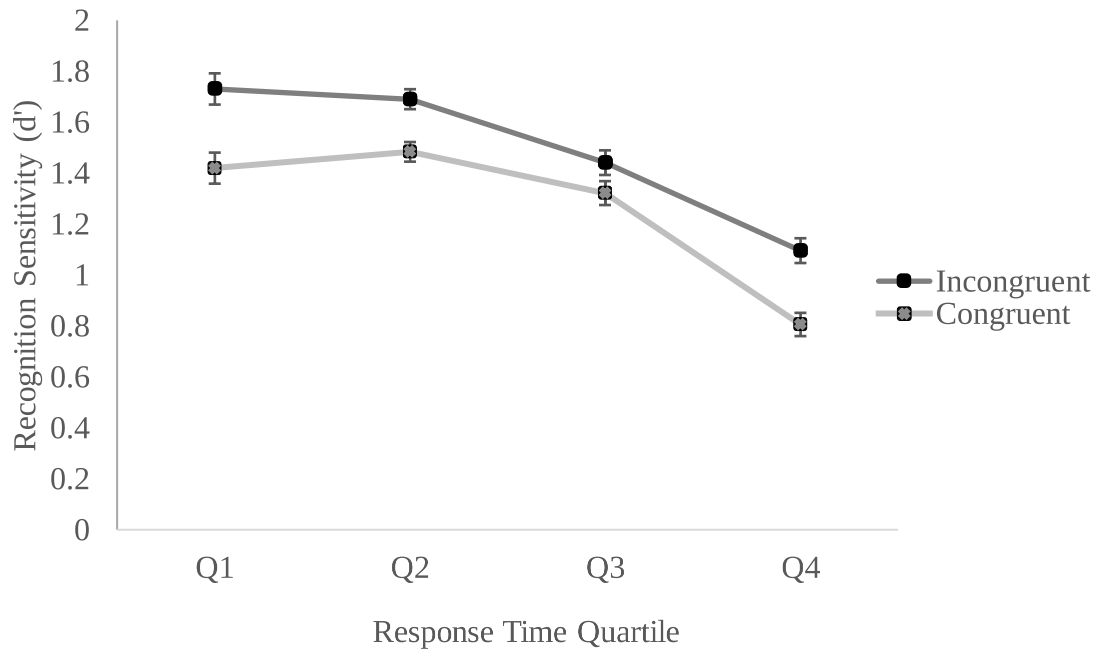

Figure 3. Recognition sensitivity (d’) for congruent and incongruent items across RT quartiles. Error bars represent Cousineau-Morey SEM (Cousineau, 2005; Morey, 2008)

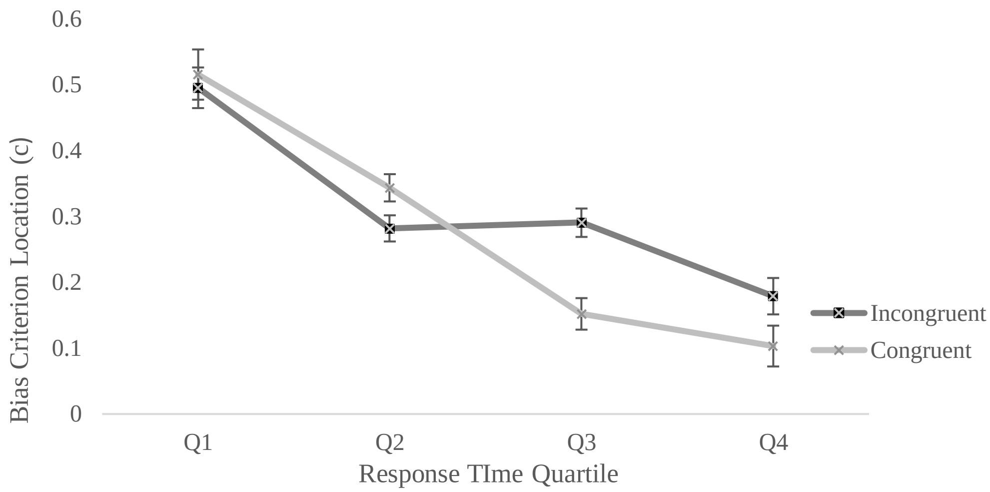

Figure 4. Bias Criterion Location © for incongruent and congruent words. A c that approaches zero and becomes negative indicates a large/more liberal response bias to name target items as old. A c that is more positive indicates a small/more conservative response bias to name target items as old. Error bars represent Cousineau-Morey SEM. (Cousineau, 2005; Morey, 2008)

Sensitivity (d'). There was a significant main effect of congruency, $F(1,115) = 38.62$, $p < .001$, $\eta_{p^2} = 0.25$. Recognition sensitivity was greater for incongruent trials (1.49) than congruent trials (1.26). There was also a significant main effect of quartile, $F(3,345) = 42.87$, $p < .001$, $\eta_{p^2} = .27$. Post-hoc polynomial contrasts showed that there was a significant linear trend across the quartiles; d' decreased as participants took longer to respond, $t(115) = -7.79$, $p < .001$. There was also a significant quadratic trend across quartiles, $t(115) = -5.59$, $p < .001$, indicating that this decrease in recognition sensitivity accelerated across the quartiles (see Figure 3).

Of note, the interaction between congruency and quartile was not significant, $F(3,345)= 1.37$, $p = .14$, indicating that recognition sensitivity was consistently greater for incongruent items than congruent items across varying speeds of recognition decisions. Also of note, the experiment variable was not significant on its own, nor did it interact with any other variable ($F < 1$, in all cases), indicating that the pattern of results described here was observed consistently across the five data sets.

Bias (c). There was a significant main effect of quartile F3, 345)= 35.13, $p < .001$, $\eta_{p^2} = .28$. Post hoc polynomial contrasts revealed a significant linear trend in bias across the quartiles, $t(115) = -6.98$, $p < .001$. As can be seen in Figure 4, the measure of response bias (c) decreased across the quartiles, indicating a more liberal bias as participants took more time to respond. There was also a significant quadratic trend in bias across the response time quartile, $t(115)= 2.76$, $p = .007$, indicating perhaps that the shift toward a more liberal bias was most pronounced between the first and second quartiles (see Figure 4)

Most important, there was also a significant interaction between congruency and quartile $F(3, 345)= 6.72$, $p < .001$, $\eta_{p^2} = .06$. For quartiles 1 and 2, there was no difference in bias for congruent and incongruent items, $t(115) = 0.48$, $p = .63$ and $t(115) = 1.63$, $p = .21$, respectively. In contrast, for quartile 3, response bias was more liberal for congruent than incongruent items, $t(115)= -3.58$, $p = .002$. For quartile 4, there was a similar pattern to quartile 3, though this difference only approached significance, $t(115)= -2.28$, $p = .07$ (see Figure 4).

Further, the experiment variable was not significant on its own, nor did it interact with any other variable ($F < 1$, in all cases), indicating that the pattern of results described here was observed consistently across the five data sets.

Proportion old analyses

To address the separate contributions of hit and false alarm rates to the effects reported above, we submitted the proportion of items judged old for each condition defined by the combination of study status (old/new), congruency (congruent/incongruent), quartile (1-4), and experiment (1-5) factors to a mixed factor ANOVA that treated study status, congruency, and quartile as within-subject factors, and experiment as a between-subjects factor. Mean proportion old for each condition, collapsed across participants, is displayed in Figure 5.

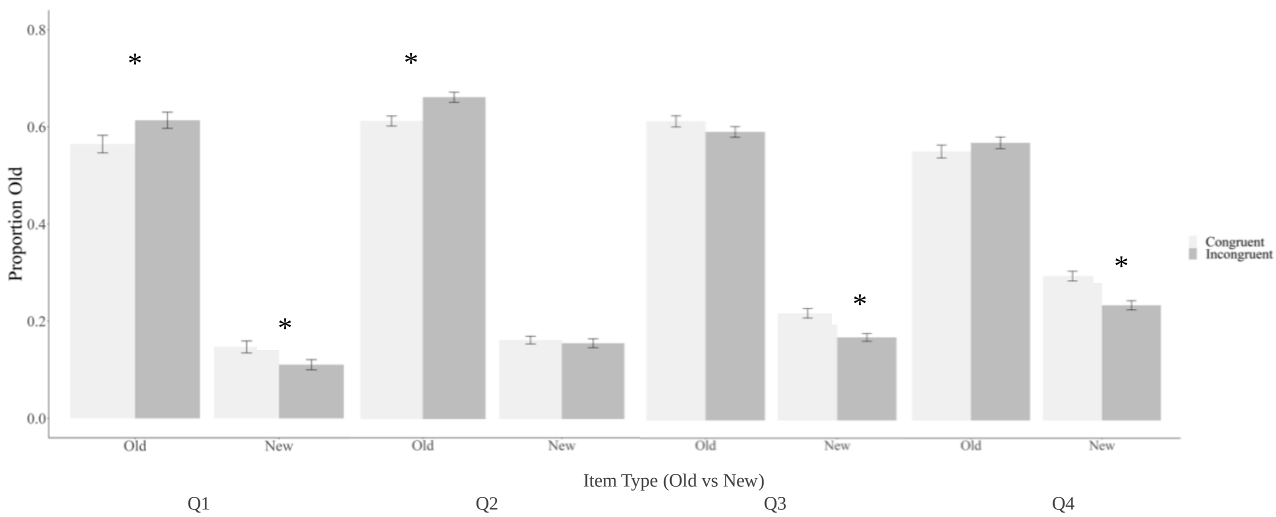

Figure 5. Proportion old responses to target words in test phase. Error bars represent Cousineau-Morey SEM (Cousineau, 2005; Morey, 2008). Asterisks represent significant differences between proportion old responses for congruent and incongruent items at α= 0.05.

In the overall analysis, there was a significant main effect of study status, $F(1,115)= 1187.78$, $p < .001$, $\eta_{p^2}= .91$, with higher hit rates than false alarm rates. There was also a significant interaction effect between experiment and study status, $F(4,115)= 3.42$, $p = .01$, $\eta_{p^2}= .11$. There were slightly larger differences between hits and false alarms for two experiments out of the five we analyzed; in these experiments, recognition tests followed each of two study lists of 60 items, rather than one recognition test following a single study list of 120 items. As can be expected, participants showed greater recognition sensitivity in these experiments because there was a shorter list of items to encode in the study phase. There were no other significant effects involving the experiment variable, all *F*s < 1.

The overall analysis also produced a significant interaction between congruency and study status, $F(1,115) = 31.08$, $p < .001$, $\eta_{p^2} = .21$. The difference between hits and false alarms was larger for incongruent items (.465) than congruent items (.400). As noted in the above signal detection analysis, this sensitivity difference for congruent and incongruent items was relatively stable across quartile; the three-way interaction between congruency, study status, and quartile was not significant, $F(3,345) = 1.83$, $p = .14$.

However, there was a significant main effect of quartile, $F(3,345) = 29.54$, $p < .001$, $\eta_{p^2} = .20$, and a significant linear trend across the quartiles, $t(115) = 6.40$, $p < .001$. As revealed in the signal detection analyses, participants responded old more often as the amount of time they took to respond increased. There was also a significant interaction between study status and quartile, $F(3,345) = 29.55$, $p < .001$, $\eta_{p^2} = .20$. To address this and other a priori issues of interest, we then analyzed hits and false alarms separately in ANOVAs that treated congruency and quartile as within-subject factors and experiment as a between subjects factor.

Hits. There was a significant interaction between congruency and quartile, $F(3,345) = 4.86$, $p = .003$, $\eta_{p^2} = .04$. Follow up t-tests that compared the hit rates for congruent and incongruent items were then conducted to describe the interaction. For the first quartile, the hit rate was significantly higher for incongruent items (.614) than for congruent items (.565), $t(115) = -2.78$, $p = .019$. For the second quartile, the hit rate was also significantly higher for incongruent items (.688) than for congruent items (.637), $t(155) = -3.13$, $p = .009$. In contrast, for the third and fourth quartiles, the hit rates did not differ significant for incongruent and congruent items (.651 vs .674 for Quartile 3; .627 vs .607 for Quartile 4), $t(155) = 1.55$, $p = .25$ and $t(155) = -1.15$, $p = .25$, respectively (see Figure 5).

False Alarms. There was a significant interaction between congruency and quartile $F(3,345) = 4.13$, $p = .007$, $\eta_{p^2} = .03$. As for the hits, follow up t-tests were conducted to describe this interaction. For the first quartile, the false alarm rate was significantly higher for congruent items (.147) than for incongruent items (.111), $t(115) = 2.64$, $p = .019$. For the second quartile, the false alarm rates were not significantly different for congruent (.169) and incongruent items (.162), $t(155) = .50$, $p = .62$. For the third and fourth quartiles, the false alarm rates were again significantly higher for congruent items than for incongruent items (.242 vs .187 for the Quartile 3; .326 vs .260 for Quartile 4), $t(115) = 3.67$, $p = .001$ and $t(115) = 4.74$, $p < .001$, respectively (see Figure 5).

Recollection and Familiarity Analyses

To address the separate contributions of recollection and familiarity judgements to the overall proportion of “old” judgments reported above, we used the independence remember-know (IRK) procedure (Yonelinas, 2002; Yonelinas & Jacoby, 1995). The IRK procedure estimates the contribution of recollection based on the proportion of trials that participants make “remember” responses. The contribution of familiarity is estimated by the proportion of trials where participants make know responses, given a remember response is not made. Estimates of recollection and familiarity were calculated for hits and false alarms, and then statistical analyses were conducted on the hit minus false alarm difference scores. Once recollection scores were computed, we submitted these scores to a mixed factor ANOVA that treated congruency (congruent/incongruent), and quartile (1-4) as within-subject factors, and experiment (1-5) as a between-subjects factor. The same analysis procedures was carried out for familiarity scores.

Recollection. There was a significant main effect of congruency, $F(1,115) = 7.70$, $p = .006$, $\eta_{p^2} = .06$. Recollection estimates were higher for incongruent items (.337) than for congruent items (.307). There was also a significant main effect of quartile $F(3,345)= 43.97$, $p <.001$, $\eta_{p^2} = .28$. Subsequent polynomial contrasts also indicated a significant linear trend across quartiles, with recollection estimates decreasing as participants took longer to make their recognition decisions, $t(115)= - 7.83$, $p <.001$ (see Table 1). Finally, there was also a significant main effect of experiment, $F(1,115) = 3.47$, $p = .01$, $\eta_{p^2} = .03$. The results of pairwise comparisons indicated significantly different recollection estimates between one experiment conducted by Davis et at. (.372) and one experiment conducted by Rosner et al. (.242), $t(115) = 3.10$, $p =.02$. However, this difference did not survive a multiple comparison correction.

Table 1: Mean proportion of Recollection Responses across response time quartiles. Standard Error is shown in parentheses

	Item Type	
Quartile	**Congruent**	**Incongruent**
Q1	0.400 (*0.017*)	0.417 (*0.016*)
Q2	0.356 (*0.010*)	0.384 (*0.011*)
Q3	0.292 (*0.012*)	0.312 (*0.011*)
Q4	0.180 (*0.015*)	0.233 (*0.015*)

Familiarity. There was a significant main effect of congruency, $F(1,115) = 15.41$, $p < .001$, $\eta_{p^2} = .12$. Familiarity estimates were higher for incongruent items (.306) than for congruent items (.247). There was also a significant main effect of quartile, $F(3, 345) = 12.66$, $p < .001$, $\eta_{p^2} = .10$. Subsequent polynomial contrasts revealed a significant quadratic trend across quartiles, $t(115) = -6.72$, $p < .001$. Familiarity estimates increased from quartile 1 to 2, and then decreased from quartile 3 to 4.

Discussion

Across all quartiles, recognition sensitivity was consistently higher for incongruent than congruent items. Importantly, this effect is observed even for quartiles 3 and 4 when there is no hit rate difference between congruent and incongruent items. Further, by examining both d' and response bias on a quartile-by-quartile basis, an interpretable pattern emerges for participants' recognition memory judgments. For the fastest two response quartiles, d' is higher for incongruent than congruent items while response bias for congruent and incongruent items does not differ. We observe a hit rate difference in these two quartiles. Conversely, for the slowest two response quartiles, the higher d' for incongruent than congruent items is observed alongside a more liberal response bias for congruent items. In these quartiles, we do not observe a hit rate difference. This pattern of performance suggests that when participants adopt a relatively liberal criterion for responding old, they become more susceptible to perceptual fluency-based misattributions. In turn, perceptual fluency-based misattributions oppose the hit rate effect caused by incongruency at study, making it more difficult to observe a congruency effect on hit rates.

Study 2: An empirical study of the orthogonal effects of congruency at study and test

The aim of this study was to tease apart the separate contributions of congruency at study and congruency at test on hit rates. In all prior studies using this method, participants were presented with two types of items. According to our putative two-process account, for both incongruent and congruent items the effects of congruency at study and at test on hit rates were acting in opposite directions. Incongruent items were more deeply encoded at study and this drives up hit rates relative to congruent items. On the other hand, incongruent items are not subject to processing fluency at test which drives down hit rates relative to congruent items.

We hypothesised that if both processes were working in the same direction to either drive up or drive down the hit rates, then we would observe a hit rate difference. By orthogonally manipulating congruency at study and at test we created four types of items. In addition to our previously used items for which study congruency matched test congruency, we created two new items types for which study and test congruency mismatched. Items that were incongruent at study and congruent at test were predicted to produce the highest hit rates while items that were congruent at study and incongruent at test were predicted to produce the lowest hit rates.

Methods

Participants

Forty-two participants (32 females, mean age = 18.7 years) from the McMaster University student pool completed the experiment. Participants could choose to receive either course credit or $10 cash as compensation. All participants had normal or corrected-to-normal vision and spoke English fluently.

Apparatus and Stimuli

The experimental program was run on a Mac computer using Psychopy experimental software (v 2022.05, Peirce, 2007, 2009). The stimuli were displayed on a 22-in Dell monitor and responses were made via keyboard. Participants were tested individually and sat approximately 50 cm from the monitor.

All stimuli consisted of two interleaved words presented in the middle of the screen against a black background. For incongruent items, the two interleaved words had different identities, whereas for congruent items the two interleaved words had the same identity (see Figure 1). The red target word was presented randomly either above or below the green distractor word. In the study phase, participants were presented with equal numbers of incongruent and congruent items. In the test phase, half of the incongruent items were presented exactly as they appeared in the study phase (i.e., they were incongruent in both the study and test phase). The other half of incongruent items from the study phase were congruent in the test phase. Similarly, half of the congruent items were presented exactly as they appeared in the study phase while the other half of congruent items from the study phase were incongruent in the test phase. In all conditions, for old test phase trials, the red target word appeared in the same position (above or below the green distractor word) in the study and test phases. The experiments used 350 five-letter words that were all high frequency nouns (Kucˇera & Francis, 1967).

Procedure

This experimental procedure was near identical to the procedure described in the preceding re-analysis. Participants completed a study phase in which they named the red target word and ignored the green distractor word for each study items. This study phase was followed by a 10-minute distractor phase, and then participants completed a recognition memory test phase that was identical to prior studies that have used this method. There was one minor change to the study phase procedure. Given the large effects of congruency on naming time in all prior studies, we used only a crude measure of naming time in the present study: the experimenter pressed a key on the keyboard at the perceived onset of the participant's naming response. The study item offset after 1000 ms, and then the experimenter also coded the participants' response as correct, incorrect, or spoil by pressing "1", "2", or "3", respectively on the computer keyboard. Incorrect responses occurred when participants named aloud a word other than the target word. Responses were coded as a spoil if a spurious noise was suspected to have set off the microphone before the response was made (e.g., coughing or stuttering before responding). In practice, it was difficult to distinguish between incorrect and spoil responses; as such the primary focus of the experimenter was to distinguish correct responses from incorrect and spoil responses.

Design

Two hundred unique two-word items were used in the experiment; 100 items were presented in both the study and test phases (old items) and 100 items were presented only in the test phase (new items). For old items, congruency was manipulated orthogonally at study and test; that is, both congruent and incongruent items at study could be either incongruent or congruent at test. This design feature is depicted in Table 2. These four conditions were created by manipulating the identity of the green distractor word that was paired with a red target word at test.

For old items that were incongruent at both study and test (II items), the red target and green distractor at study were different words; an identical item (same red target, same green distractor) was then presented in the test phase. For old items that were congruent at both study and test (CC items), the red target and green distractor at study were identical words; an identical item was then presented in the test phase. For old items that were incongruent at study and congruent at test (IC items), the red target and green distractor at study were different words; both the red target and green distractor in the test phase matched the identity of target word from the study phase. For old items that were congruent at study and incongruent at test (CI items), the red target and green distractor at study were identical words; the red target word in the test phase matched the red target word from the study phase but mismatched the identity of green distractor word in the test phase.

For new items, half were congruent and half were incongruent. For congruent items, the red and green words had the same identity. For incongruent items, the red and green words had different identities.

The 200 items were constructed using a set of 350 five-letter high frequency words. The 350 words were randomly divided into 14 lists of 25 words for counterbalancing purposes. There were 14 different roles that a given word could play; the experiment was counterbalanced such that across each 14 participants, each word appeared in each of the 14 possible roles.

In the study phase, a total of 25 items were presented in each of the four conditions defined by factorially combining the congruency at study and congruency at test variables, for a total of 100 study phase items. These items were intermixed randomly in the study phase. In the test phase, these 100 old items were randomly intermixed with 50 congruent and 50 incongruent new items for a total of 200 recognition trials.

Table 2: Categories of item types for items which appeared in both the study and test phases (i.e. Old items).

		Congruency at Study	
		Incongruent	Congruent
Congruency at test	Incongruent	II	CI
	Congruent	IC	CC

Results

Participants correctly named 93.7% of trials in the study phase. Mean response times for correctly named target words were subjected to a one-tailed paired sample *t*-test. This analysis revealed significantly slower responses for incongruent items (982 ms) than for congruent items (849 ms), $t(41) = 15.9$, $p < .001$, d = 2.45.

Signal Detection Analyses

Signal detection methods were used to analyze recognition sensitivity (d') and bias (c). These d' and c values were computed for each condition and then submitted to an ANOVA that treated congruency at study (congruent/incongruent) and congruency at test (congruent/incongruent) as within-subject factors.

Sensitivity (d'). This analysis revealed a significant main effect of congruency at study, $F(1,41) = 6.17$, $p = .017$, $\eta_{p^2} = 0.13$. Recognition sensitivity was greater for items that were incongruent (1.37) than congruent (1.25) in the study phase.

Bias (c). This analysis revealed a significant effect of congruency at test, $F(1,41) = 7.65$, $p = .008$, $\eta_{p^2} = 0.16$. The bias measure was significantly lower (i.e., more liberal) for congruent items (0.001) than for incongruent items (0.124). There was also a significant effect of congruency at study, $F(1,41) = 6.174$, $p = 0.017$, $\eta_{p^2} = 0.13$. Congruent items (0.092) had a significantly higher (i.e., more conservative) criterion than incongruent items (0.033).

Proportion Old Analyses

We also conducted separate analyses of the hit and false alarm rates to assess predictions of the two-process account. Mean hit and false alarm rates, collapsed across participants, are presented in Figure 6.

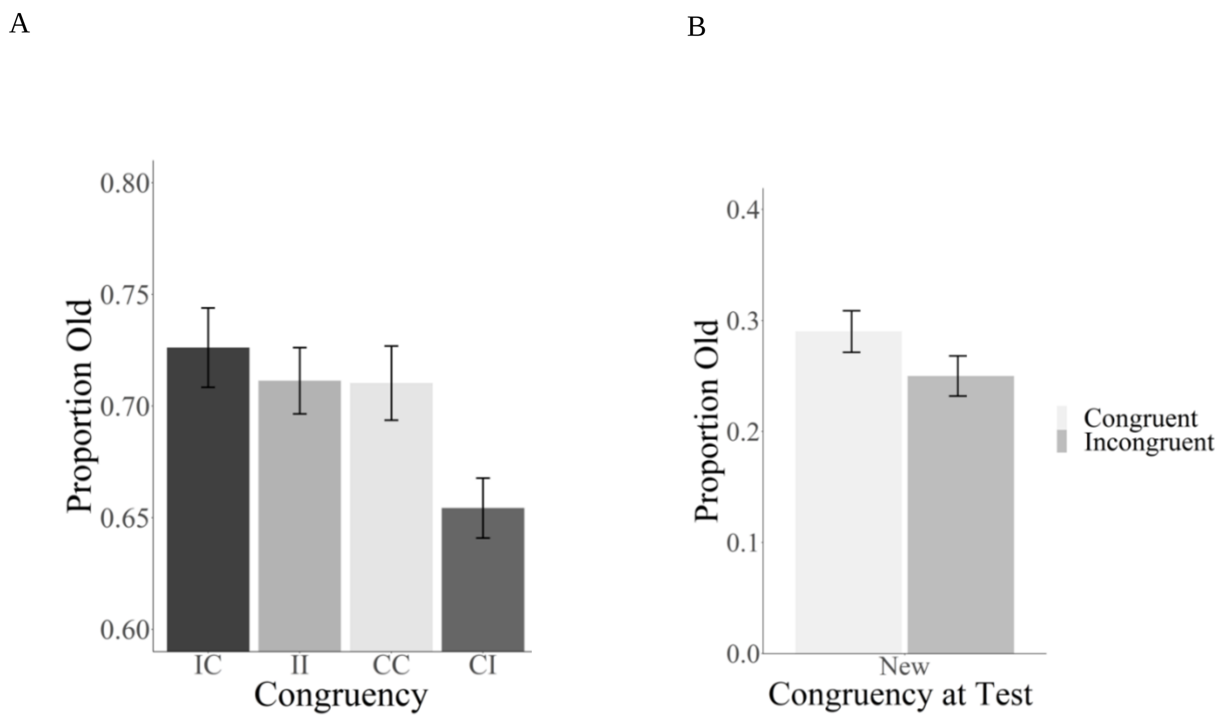

Figure 6. Proportion old responses to target words in the test phase. Error bars represent Cousineau-Morey SEM (Cousineau, 2005; Morey, 2008).

Hits. Hit rates in each condition were submitted to a repeated measures ANOVA that treated congruency at study (congruent/incongruent) and congruency at test (congruent/incongruent) as within subject variables. There was a significant main effect of congruency at study, $F(1,41)= 6.39$, $p =.015$, $\eta_{p^2} = 0.13$. The hit rate for incongruent items (.719) was higher than for congruent items (0.682). The effect of congruency at test approached significance $F(1.41) = 3.05$, $p = .088$. Items that were congruent at test had a hit rate of .718 while incongruent items at test had a hit rate of .683.

Two separate a priori comparisons were also conducted to assess predictions of the two-process account. First, the hit rates were not significantly different for the II (.711) and CC (.710) conditions, $t(41) = 0.035$, $p = .972$. Second, there was a significant difference between the hit rates for the IC (.726) and CI (.654) conditions, $t(41) = 2.76$, $p = 0.009$ (see Figure 6).

False Alarms. A paired sample t-test on false alarm rates revealed a significant effect, $t(41)= 2.42$, $p = .002$. False alarms were higher for congruent items (0.29) than for incongruent items (0.25) (see Figure 6).

Recollection and Familiarity Analyses

We used the independence remember-know (IRK) procedure described earlier to compute estimates of recollection and familiarity. These estimates of recollection and familiarity were submitted to repeated measures ANOVAs that treated congruency at study and congruency at test as within-subject factors. The only significant effect in these analyses was the main effect of congruency at study on recollection, $F(1,41) = 11.34$, $p = 0.002$, $\eta_{p^2} = 0.22$. Recollection was greater for incongruent items (.326) than for congruent items (.277). There were no significant effects in the analysis of familiarity.

Discussion

The goal of this study was to examine the separate contributions of congruency at study and test on hit rates. First, incongruent items at study were named slower than congruent items. This result is consistent with the idea that processing disfluency at study was greater for incongruent items than for congruent items. Second, recognition sensitivity was higher for incongruent than congruent items, as observed in prior studies (Rosner et al., 2015; Davis et al., 2020) and highlighted in the earlier re-analysis. Third, false alarms were higher for congruent items than for incongruent items, pointing again to a role for fluency misattribution at test in recognition decisions. Fourth, for two conditions in which incongruency at study and congruency at test produced effects that were in opposition (i.e., the CC and II conditions), the hit rates did not differ. Finally, for two conditions in which these two congruency-based processes could work in concert (i.e., the IC and CI conditions), we observed a hit rate difference with higher hits for IC items than for CI items.

General Discussion

Recent studies have called to question whether recognition memory is superior for items that elicit cognitive conflict at study. In particular, Jimenez et al. (2020) cited a missing hit rate difference as evidence that cognitive conflict in the method of Rosner et al. (2015) may not affect memory performance. The goal of this research program was to address this concern by focusing on two issues, each of which was examined in two studies reported here.

First, we examined further whether recognition sensitivity is indeed greater for incongruent than congruent items in the selective attention method developed by Rosner at al. (2015). A re-analysis of a large set of data collected using this method revealed a strong and consistent pattern of higher recognition sensitivity for incongruent items. A new empirical study also addressed this issue, and here again we observed greater recognition sensitivity for incongruent items at study than for congruent items at study.

Second, we focused on the puzzling finding that hit rates for incongruent and congruent items are sometimes equivalent; can a two-process approach explain why there is not always a hit rate advantage for incongruent items? In our re-analysis, we examined whether a time-course analysis would tease apart these two processes. By dividing participants' recognition memory responses into response time quartiles, we found that there was a significant hit rate difference between incongruent and congruent items in the fastest two quartiles. In contrast, we found no such hit rate difference for the slowest two quartiles—however we did observe higher false alarm rates for congruent than incongruent items in the two slowest quartiles. All told, this pattern of hit and false alarm rates is consistent with the view that recognition sensitivity (d') is higher for incongruent items than congruent items across all quartiles, but that perceptual fluency at test also biases participants to respond old to congruent items in the slowest two quartiles. Our new empirical study aimed to tease apart these processes by orthogonally manipulating congruency at study and at test. To examine the separate contributions of processing difficulty (i.e., incongruency) at study and perceptual fluency (i.e., congruency) misattributions at test to recognition memory decisions, we created two new conditions aimed at either driving up (IC) or pushing down (CI) hit rates in concert. As predicted, the results revealed a significant difference in hit rates for these two conditions. At the same time, and also as predicted, the two conditions that featured one of the two processes working in opposition to the other (i.e., the II and CC conditions) revealed no hit rate difference (see also Davis et al., 2020).

Two processes determine if a hit rate difference is observed

These results are consistent with the view that incongruency at study does lead to a benefit in recognition sensitivity (Rosner et al., 2015; Davis et al., 2020; Krebs et al., 2015). One account of this effect is that participants engage in trial-by-trial adaptations in their deployment of attentional resources depending on congruency (or cognitive conflict associated with a given trial) at study (Botvinick et al., 2001). An upregulation in attention at study then produces a benefit in recognition sensitivity for incongruent items. However, this upregulation of attention on incongruent trials is just one of two congruency-based processes that determines whether a hit rate difference is observed. The results also support the view that congruency at *test* enhances perceptual fluency, and this enhanced perceptual fluency may be misattributed to prior experience (Jacoby & Dallas, 1981; Jacoby & Whitehouse, 1989).

This two process account can be used to explain the relationship between hit rates and false alarm rates that emerged in our quartile analysis (see Figure 5). First, note that the fastest two response time quartiles were associated with higher recognition sensitivity and more conservative response bias than the slowest two response time quartiles. This profile is generally consistent with the idea that recognition decisions for the faster response time quartiles are dominated by retrieval of specific information from memory, whereas recognition decisions for the slower response time quartiles are less confident and include inferences based on perceptual fluency at test. Second, note that for the two slowest quartiles (Q3 and Q4) we observed both equivalent hit rates and significantly greater false alarms for congruent than incongruent items. We propose that in these quartiles, fluency-based misattributions play a substantial role in recognition memory decisions to drive up both the hit rate and false alarm rate for congruent items. Conversely, in the two fastest quartiles (Q1 and Q2) we observed either equivalent false alarms (Q2) or a small false alarm difference (Q1). We suggest that fluency-based attributions play a much smaller role in these recognition decisions; rather, retrieval of specific information from memory is the dominant process underlying memory decisions. It then follows that neither the hit nor false alarm rates for congruent items are driven up by fluency-based responding on congruent test trials, which allows the hit rate difference between congruent and incongruent items to be observed.

An exception to this clear-cut data pattern occurs in Q1, where the hit rate difference is accompanied by a significantly greater false alarm rate for congruent than incongruent items (see Figure 5). We propose a process separate from fluency misattributions to explain this false alarm difference. In particular, there is good support in the memory literature for participants using the absence of clear recollection as strong evidence against an item being old (Brown et al., 1977; Vokey & Read, 1992). By this view, if participants have no clear recollection of an item at test, they assess its memorability, or how likely they would have been to remember it if had been presented in the study phase. When an item is judged at test to be high in memorability, and yet not remembered, this combination can make it more likely that the item is judged to be new (Brown et al., 1977). This idea was supported by Brown et al. (1977), who presented participants with study lists comprised of high and low frequency words. In a following recognition test, subjects rated each word based on the probability that it was presented at study. As predicted, low frequency distractors were more likely to be rejected than high frequency distractors. They suggested that because low frequency words have a higher memorability, the absence of a memory associated with a low frequency word is strong evidence to reject it. Participants in our study may be relying on a similar process to confidently and quickly reject some of the new incongruent items.

When does cognitive conflict produce memory enhancements?

In our study and others using Rosner et al.'s (2015) selective attention task, we find better memory for stimuli which elicit cognitive conflict. However, as highlighted by Jimenez et al. (2020), these effects are not always observed in selective attention tasks. It seems that it is not enough to simply increase processing difficulty and elicit cognitive conflict to observe memory benefits.

As proposed by Hirshman et al. (1994), processing difficulty on a perceptual level must force participants to engage in compensatory processing (i.e., additional higher-level processing) for memory to be enhanced. In their study, words were presented either intact or followed by a pattern mask after a very brief delay and participants were instructed to read them aloud. The results of a recognition memory test revealed superior memory for the perceptually difficult-to-process masked words. Hirshman et al. (1994) suggested that delaying mask onset decreased the perceptual difficulty associated with reading the words, to the point that compensatory processing was not required to the same extent. As such, the mnemonic benefit associated with masking was reduced.

It is plausible that the perceptual disfluency associated with reading incongruent items in our study required an increase in attention to ensure successful completion of the task. This increase in attentional resources may have signaled to participants' cognitive systems a need to recruit higher level semantic information during encoding as a form of compensatory processing. It would then follow that at test, participants would have access to a stronger memory trace and recognise these items at a higher rate. This idea is supported by Ptok et al's. (2019) suggestion that cognitive conflict must direct attention to the semantic meaning of to-be-tested stimuli for a memory benefit to ensue. More broadly, if selective attention is directed to features that are most relevant to success on a task, then a memory benefit is observed for conflict-eliciting items.

An important boundary condition for these memory enhancements associated with processing difficulty is that they are largely observed when study tasks involve highly automatized tasks, such as word naming in the present study. When participants are instructed to engage in less fluent tasks during encoding, such as spelling words aloud instead of reading, the memory benefit for difficult-to-process stimuli is often eliminated (Westerman & Greene, 1997). In these tasks, processing difficulty manipulations may not produce substantially different involvement of encoding processes that extract meaning. Subtle processing difficulty manipulations which direct attention to task-relevant information differentially in the easy and difficult encoding conditions may be critical to producing superior memory performance for the difficult encoding condition. In the case of our congruency manipulation, fluent processing during naming of congruent study items may result in a naming response without accessing meaning, whereas disfluent processing during naming of incongruent items may be sufficient to cue the compensatory processing that results in more meaningful encoding. However, if the encoding task was something other than one that required well-learned and highly fluent naming processes, the difficulty associated with the task itself could mitigate differential access to meaning during encoding of congruent and incongruent items.

Conclusion

In summary, we found strong evidence that a combination of disfluency-based encoding superiority at study and fluency-based misattributions at test determine whether a hit rate difference is observed in the Rosner et al. (2015) method. A null hit rate difference may indicate that the effect of superior encoding of incongruent items is masked by a tendency to respond "old" to congruent items. With a firm understanding of these two processes, we can conclude that recognition sensitivity is consistently greater for incongruent items at study. More broadly, this result adds to a growing literature on conflict related memory enhancements; when conflict for a difficult-to-process item selectively directs attention to a level of processing that is relevant to a subsequent memory test, better memory performance for these difficult-to-process items is the outcome.

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