PERCEPTUAL DIFFICULTY EFFECTS ON MEMORY

PERCEPTUAL DIFFICULTY EFFECTS ON MEMORY:
THE BENEFIT OF INCONGRUENCY FOR SUBSEQUENT RETENTION

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LAY ABSTRACT

The way we pay attention to information influences how well we remember it later. Although this link seems intuitive, research on this topic has led to a complex literature with mixed results and several different theoretical perspectives. Specifically, several memory effects have been reported that describe better memory performance for items that were difficult to process during learning compared to items that were easy to process. The theoretical goals of this thesis were to review several of these memory effects and to offer a more unified conceptual understanding of their underlying cognitive processes. The empirical goal of this thesis was to examine one such memory effect and place the findings in the context of the conceptual frameworks discussed.

ABSTRACT

This thesis examined the intersection between processing difficulties at encoding and subsequent retention. A number of reported effects describe the finding of better memory performance for items that were difficult to process in an earlier study phase compared to items that were easy to process—a finding broadly captured by the desirable difficulty principle (Bjork, 1994; Bjork & Bjork, 2011). The Introduction provides an overview of several of these effects, as well as an evaluation of theoretical frameworks that may help us understand the cognitive processes that may be shared across them. The empirical work focuses specifically on one memory effect—better recognition for targets formerly presented on incongruent as opposed to congruent trials in a selective attention task. The effects reviewed in the Introduction, including the one studied in the three empirical chapters, all involve difficulty in processing target information in a relatively simple perceptual identification task. The work covered in this thesis demonstrates that manipulations of perceptual features reliably benefit subsequent memory when the difficulty directs additional processing toward higher-order features. Furthermore, the memory test must appropriately tap into these conceptual feature representations at retrieval. The implications of these findings is discussed in the context of the desirable difficulty literature, as well as the attention and memory literatures more broadly.

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DECLARATION OF ACADEMIC ACHIEVEMENT

The Introduction of this sandwich thesis is a review article to be submitted for publication in the future, which was conceptualized and written by Hanae Davis and her supervisor Dr. Bruce Milliken.

Chapter 2 is a published empirical article by Hanae Davis, Drs. Tamara Rosner, Maria D'Angelo, Ellen MacLellan, and Bruce Milliken (*Psychological Research*, 2019). Experiment 1 was designed and conducted by Tamara Rosner and Bruce Milliken. Hanae Davis was involved in the conceptualization, design, programming, data collection, and analyses of all other experiments. The writing of this manuscript was completed by Hanae Davis and Bruce Milliken, with input from the other authors.

Chapters 3 and 4 are empirical articles in manuscript form for publication. The experiments included in these chapters were conceptualized, designed, programmed, conducted, and analysed by Hanae Davis with guidance from Bruce Milliken. The writing of these manuscripts was completed by Hanae Davis and Bruce Milliken, with input from Dr. David Shore on Chapter 3. Analyses in Chapter 4 incorporated input from Dr. Karin Humphreys.

The General Discussion of this thesis was conceptualized and written by Hanae Davis, with edits from Bruce Milliken.

Chapter 1: General Introduction

The broad goal of this thesis is to examine the association between processing difficulty at encoding and long-term retention. Many prior studies in the memory literature point to an interesting empirical regularity: Memory performance is often better for items that were difficult to process than for items that were easy to process in a preceding learning phase. Findings of this type have come to be known as desirable difficulties (Bjork, 1994; Bjork & Bjork, 2011). This thesis contains three empirical chapters that focus on one particular desirable difficulty—better recognition for items that appeared as targets on incongruent as opposed to congruent trials in a preceding selective attention task (Rosner, D'Angelo, et al., 2015). The remainder of this Introduction provides context for this empirical work by: (a) summarizing the literatures on several desirable difficulty effects that could be related to the effect of interest here; and (b) discussing several theoretical frameworks from the attention and memory literatures that could be used to explain why these desirable difficulty effects occur.

Desirable Difficulties

The concept of "desirable difficulties" was introduced by Bjork (1994) to capture the idea that difficult task demands—varying encoding contexts, reducing feedback at study—are often associated with robust long-term retention. The desirable difficulty principle applies to a range of well-studied empirical findings in the memory literature, including the spacing effect (better memory for spaced than massed study opportunities), the testing effect (better memory for test than restudy opportunities), and the generation effect (better memory for self-generated than provided information; Bjork & Bjork, 2011). These findings point to the possibility that tasks that are high in processing complexity sometimes cue cognitive processes that contribute to the task at hand, but that also benefit long-term retention. It is important to note that the observed association between encoding difficulty and benefits in retention is not meant to imply that task difficulty causes the improved retention—task difficulty is something that we can measure (e.g., by measuring task speed and accuracy) and presumably has many underlying causes, so should not itself pretend to be a precise cause in any particular theory. Rather, our efforts should aim at understanding how it is that task difficulty and improved long-term retention are in some way associated (Dunlosky & Mueller, 2016). An understanding of this association requires research into fundamental learning, memory, and attention processes that mediate this association.

There has been increasing recent interest in the association between processing difficulty and long-term retention/comprehension using verbal materials and tasks that require participants to remember and understand in ways that are common in educational contexts (e.g., Diemand-Yauman et al., 2011). The basic idea driving much of this research is that even subtle disfluencies in the processing of verbal text can be detected metacognitively, and met with an increase in encoding effort that benefits ultimate retention and comprehension. If this idea were correct and complete, then it ought to have spawned a wide range of consistent and supportive empirical demonstrations. In fact, it has instead produced a literature with many inconsistencies, and only modest support for the idea that increasing the difficulty of perceptual identification of verbal material improves long-term retention and comprehension (Kuhl & Eitel, 2016). Apparently, the association between perceptual identification difficulty and long-term retention and comprehension is more complex than originally conceived.

The following section reviews the relevant literature on this topic, with the aim of better understanding processes that produce ‘desirable difficulty’ effects in perceptual identification using verbal materials. In response to the complexity of this issue, I have restricted this review to studies that examine perceptual identification difficulty effects on long-term retention, and hope that others will see merit in performing a similar review of studies that measure comprehension. The following section examines various methods of manipulating perceptual identification difficulty and consequent effects that have been reported in long-term retention.

Perceptual Identification Difficulty Effects on Remembering

I review five methods used to study the relation between perceptual identification difficulty and long-term retention. Each of the methods manipulates performance difficulty in a first phase (the learning phase), and then measures memory performance in a second phase (the test phase). For all of the methods, I focus on whether memory performance in the test phase is better for the more difficult condition from the learning phase, and whether such effects might be caused by similar processes across the various methods. Perceptual identification difficulty is manipulated in the learning phase with perceptual degradation (Yue et al., 2013; Rosner et al., 2015), visual masking (Nairne, 1988; Hirshman et al., 1994), target/distractor congruency (Krebs et al., 2015; Ptok et al., 2019; Rosner, D'Angelo, et al., 2015, Ortiz-Tudela et al., 2017), stimulus repetition (Rosner et al., 2018), and orthographic distinctiveness (Zechmeister, 1969; Hunt & Elliot, 1980; McDaniel et al., 2011). These methods have been discussed previously in isolation (but see McDaniel & Bugg, 2008), but here I examine them together with the goal of identifying whether the effects they produce share underlying processes.

Perceptual Degradation

The first method considered involves perceptual identification made difficult by degrading perceptual information for to-be-remembered items. The general idea is that perceptual degradation of study item features reduces the fluency with which they are processed. The perception of disfluent processing during learning may then trigger some form of adaptation that strengthens long-term retention. Three variants of degradation that influence ease of perceptual identification are considered here: (1) manipulation of font, (2) manipulation of visual blur, and (3) manipulation of auditory spliced silence.

Difficult-to-Read Font. Early work on font manipulation effects originated from a study by Alter et al. (2007) aimed at human reasoning. They presented items of the Cognitive Reflection Test (CRT; Frederick, 2005) to one group in an easy-to-read font (Myriad Web, black, 12-point) and to a second group in a difficult-to-read font (Myriad Web, 10% gray, 10-point, italicized). Participants in the difficult-to-read font group answered more questions correctly than participants in the easy-to-read font group. Alter et al. proposed that presentation of verbal material in a difficult-to-read font produces an experience of disfluency. This disfluency then serves as a metacognitive signal that intuitive System 1 reasoning processes are insufficient and more analytic System 2 reasoning processes are required (Alter et al., 2007; James, 1890/1950). Greater engagement of System 2 processes for the disfluent items then explains why performance on the reasoning task was superior for these items.

This type of font manipulation was extended to measure effects on retention by Diemand-Yauman et al. (2011). In Experiment 1, they used a between-groups design to examine whether three fictitious taxonomic categories each with seven features could be learned more effectively when presented in a difficult-to-read font (Comic Sans or Bodoni, 60% grayscale, 12-point) than when presented in an easy-to-read font (Arial, black, 16-point). Retention was tested by asking participants questions about features associated with particular taxonomic categories. Participants in the difficult-to-read font group answered more retention questions correctly than participants in the easy-to-read font group. In Experiment 2, learning material (worksheets and PowerPoint slides) from six high school classes was subject to a font manipulation across two sections of the same course taught by the same instructor. The learning material was unchanged or changed to reduce the fluency with which it could be read. Fluency was reduced either by switching the learning material to difficult-to-read fonts (Haettenschweiler, Monotype Corsiva, Comic Sans Italicized) or by moving the learning material up and down slightly while it was being copied. Class assessments revealed higher scores for the difficult-to-read group than for the easy-to-read group. These results are consistent with the proposal that difficult-to-read fonts promote greater engagement and deeper encoding (Craik & Tulving, 1975) of the learning material, and that these processing consequences can influence retention (Experiment 1) and perhaps also comprehension (Experiment 2).

Although the finding reported by Diemand-Yauman et al. (2011) seems compelling, conceptual replication attempts have revealed mixed results. Several attempted replications of Diemand-Yauman et al. have indeed produced superior retention (and perhaps also comprehension) of learning material presented in a difficult-to-read font than in an easy-to-read font (French et al., 2013; Weltman & Eakin, 2014; Lehmann et al., 2016). However, other studies have reported null effects of font manipulations on subsequent retention (Magreehan, et al., 2015; Eitel & Kuhl, 2015; 2016). It seems clear that not all font manipulations produce a benefit in retention for learning material presented in difficult-to-read font, and those that do may not be robust to variations in encoding or retrieval conditions.

Perhaps more important, studies that are close procedural replications of Diemand-Yauman et al. (2011) have also failed to replicate the original effect. Rummer et al. (2016) reported the results of three experiments that required learning of fictitious taxonomic categories with seven features each, much like the Diemand-Yauman et al. study. The fonts used were identical to Experiment 1 of the Diemand-Yauman et al. study (Arial, black, 16-point vs. Comic Sans, 60% grayscale, 12-point). Yet, in none of the three experiments was recall different for the difficult-to-read and easy-to-read font items. Taken together, these studies demonstrate that difficult-to-read fonts do not reliably affect processing in a way that improves long-term retention (Kuhl & Eitel, 2016).

Visual Blur. Yue et al. (2013) examined the mnemonic effects of visual degradation on metacognition and free recall using a perceptual blurring manipulation. Participants made judgments of learning (JOLs) for visually intact (clear) and degraded (blurry) single words in an initial study phase, followed by a memory test. Across multiple experiments that varied several methodological features, they consistently observed higher JOLs for clear trials than blurry trials, but no difference in subsequent memory performance (in one case, recall was better for clear words). Extending stimulus duration (to allow for longer study time), using blocked rather than mixed lists (to prevent a general upregulation in processing that benefits both trial types), and switching from recall to recognition at test (recognition is thought to be more sensitive to disfluency manipulations) all failed to produce a memory benefit for blurry words. Blurring of words may increase disfluency (as measured in the JOLs), but does not necessarily cue increased higher-order (i.e., semantic) processing that benefits retention.

Strukelj et al. (2016) examined two reasons for why these degradation effects are difficult to observe: (1) effects may be too subtle to capture at a coarse outcome level, and (2) effects may not occur reliably for all learners. Participants in their study were presented paragraph text in either clear font or blurry font during the learning phase and completed a free recall task. Eye movements during the learning phase and working memory capacity (WMC) were measured. A key prediction was that a disfluency benefit in subsequent memory might occur only for participants with high WMC, due to the availability of additional resources to process blurred text. However, free recall did not differ between clear and blurry text groups, and WMC did not moderate this effect. Moreover, total reading times and average eye fixations did not differ between groups. Although reading times across the learning phase were initially faster in the blurry text group (suggesting lower initial effort) and reversed to being faster in the clear group later on, no corresponding pattern was observed in subsequent recall. Blurred text may serve as a cue to adjust online processing, but this study also failed to identify when processing adaptations in response to perceptual blur influence subsequent retention.

Some progress toward this end was reported by Rosner et al. (2015). Participants were presented clear and blurry single words in a learning phase and then completed a surprise recognition memory task. Naming times in the study phase were slower for blurry than clear words, which, akin to the JOL result in Yue et al. (2013), indicated that they were more difficult to process. However, unlike the Yue et al. study, recognition sensitivity was higher for blurry than clear words. Rosner et al. (2015) discovered two differences in method to be critical to the different results reported in their study and in the study of Yue et al. (2013). First, the degree of blur used by Rosner et al. (2015) was noticeably higher than that used by Yue et al. (2013). A direct comparison of the influence on subsequent retention of these two degrees of blur confirmed this to be a crucial issue: There was no difference in recognition between clear and blurry words with the degradation level of Yue et al., but there was better recognition for blurry than clear words when a higher level of blur was used. A memory benefit for blurry stimuli, at least for single words in recognition, appears to depend on level of degradation. Second, Yue et al. asked participants to report JOLs on an item-by-item basis during the study phase, whereas participants in the first several experiments of the Rosner et al. study did not report JOLs. Again, a direct comparison of the influence on subsequent retention of participants reporting versus not reporting JOLs for each item in the study phase revealed that report of JOLs eliminated the superior recognition for blurry over clear items regardless of the level of blur (for similar memory consequences of item-by-item JOLs, see Begg et al., 1991; Besken & Mulligan, 2013, 2014; Matvey, Dunlosky, & Guttentag, 2001). These results suggest that an effect of blurred font on subsequent memory is sensitive to subtle design features but can be observed reliably under certain conditions.

Auditory Spliced Silence. Perceptual degradation effects on subsequent retention have also been reported in the auditory domain. Besken and Mulligan (2014) presented participants with auditory single word probes that were degraded with inter-spliced silences or left intact. Lower identification accuracy and slower naming times on degraded trials confirmed that processing was more difficult for degraded than intact trials. Subsequent memory performance was better for degraded than intact words in both free recall and recognition (but see Susser et al., 2013). As with the effects observed with visual blur, the benefit in recognition for degraded auditory items was observed when aggregate JOLs were made (one judgment at the end of the study phase) but was eliminated when item-by-item JOLs were made.

Perceptual Interference

The second method considered here is perceptual identification made difficult by presenting verbal information briefly followed by pattern masking. Nairne (1988) first demonstrated that subsequent memory is better for words presented briefly and pattern masked than words left unmasked in an initial study phase (see also Hirshman & Mulligan, 1991; Hirshman et al., 1994; Mulligan, 1996; 1999). This finding is now commonly referred to as the perceptual interference effect. It appears to be driven by identification difficulty rather than the mask itself as subsequent recall is superior for masked than unmasked words when mask onset occurs shortly after the word onset (83 ms), but not when mask onset follows word onset by a longer interval (266 ms; Hirshman et al., 1994). A longer interval between word and mask onsets presumably reduces identification difficulty. Thus, processing adjustments that lead to memory consequences may hinge on the potential for interference of perceptual identification processes.

The perceptual interference effect has been observed in conceptually-driven explicit tasks such as recognition, free recall, and category-cued recall, but not in implicit or data-driven explicit tasks such as category-exemplar generation or rhyme recognition. The effect may not be driven by differences in encoding of low-level visual information per se (Hirshman & Mulligan, 1991; Mulligan 1996), and instead may reflect adaptations involving higher-order (e.g., lexical or semantic) representations. The perceptual interference effect appears to be unaffected by the temporal interval between study items (Hirshman et al., 1994) and by pleasantness rating judgments made for study items (Mulligan, 1996), suggesting that it is not driven by inadvertent post-perceptual rehearsal or semantic elaboration differences for masked and unmasked items (Mulligan, 1996). Furthermore, source discriminability (whether a test word was presented masked or unmasked at study) is no better for masked than unmasked words, suggesting that the interference manipulation does not enhance memory for spatio-temporal contextual details but rather for acontextual details of the word itself (Mulligan, 1996; see also Mulligan 1999). Enhancement of acontextual details of masked items is broadly consistent with predictions derived from an item-relational framework (Mulligan, 1999;

see Hunt & Einstein 1981, Hunt & McDaniel, 1993). A detailed discussion of this issue is provided in a later section.

Together, these findings are consistent with the idea that the perceptual interference effect is due to differential processing of higher-order details of the word that are conceptual in nature. This idea is captured by the *compensatory processing account*, according to which the mask interferes with perception of visual information, which is in turn compensated by increased involvement of higher-order non-visual features (i.e., phonological/lexical/semantic) in the identification process. It is the differential involvement of this higher-order information in the masked and unmasked conditions that produces the memory benefit for masked words. Indeed, Westerman and Greene (1997) failed to observe a perceptual interference effect for very low frequency words and for nonwords. Both of these results are consistent with the compensatory processing account, and in particular with the involvement of lexical representations.

Congruency

Another class of perceptual identification difficulty during encoding that has implications for subsequent memory performance involves congruency—the match (or mismatch) between target and distractor information. Under congruent conditions, the target and distractor information match and direct participants to the same (correct) response. Under incongruent conditions, the target and distractor information mismatch, and greater control is required to arrive at the correct response. Three task variants that fit this description are discussed here, in which congruency manipulations are produced with: (1) spatial overlap, (2) semantic categories, and (3) spatial expectancies.

Spatial Overlap. Two recent studies presented target and distractor items that were spatially overlapping, and asked participants to attend to the target while ignoring the distractor (Krebs et al., 2015; Rosner, D'Angelo, et al., 2015). In a study by Krebs et al. (2015), the study phase involved a face-word Stroop-like task in which participants completed a gender discrimination response for male and female face images. The distractor word "male", "female", or "house" was superimposed on each image, creating congruent (e.g., "male" over a male face), incongruent (e.g., "male" over a female face), and neutral trials (e.g., "house" over a female face). The test phase was a surprise recognition test of the previously seen faces from the study phase. Rosner et al. (2015) conducted a conceptually similar study. The study phase trials consisted of a red target word spatially interleaved with a green distractor word. The identities of the two words matched on congruent trials and were different on incongruent trials, and participants read the target word aloud. The test phase was a surprise recognition test of the target words. As expected, response times to targets in the study phase were slower on incongruent than on congruent trials in both studies. More important, subsequent recognition was better for targets formerly presented on incongruent than on congruent trials in both studies.

One account of these congruency effects in recognition makes reference to adaptation in cognitive control. By this view, incompatible responses elicited by distractors on incongruent trials give rise to conflict, which signals an upregulation of cognitive control to ensure selection and execution of the correct response (Botvinick et al., 2001; Botvinick, 2007). This additional control on incongruent trials may in turn enhance memory encoding for targets on those trials (Krebs et al., 2015; Rosner, D'Angelo, et al., 2015; see also Verguts & Notebaert, 2009).

Although this conflict monitoring model (Botvinick et al., 2001) appears to fit the basic congruency effects in recognition memory that have been reported (Krebs et al., 2015; Rosner, D'Angelo, et al., 2015), this model was developed to account for congruency effects in online performance (i.e., response times and errors), and a more thorough evaluation of the fit of this model to the recognition results is needed. The conflict monitoring model accounts nicely for the finding that congruency effects in online performance are affected by list context, both at a list-wide level (Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; for a review see Bugg & Crump, 2012) and at a trial-by-trial level (Gratton et al., 1992; for a review see Carter & van Veen, 2007; Egner, 2007). Davis et al. (2020; see Chapter 2 of this thesis) recently examined whether online adjustments in cognitive control that are sensitive to list context also translate to memory performance. They found that the magnitude of the congruency effect in recognition was unaffected by the relative proportions of congruent and incongruent trials presented in the study list, suggesting that the congruency effect in recognition does not hinge on list context. Furthermore, a reanalysis of all available data examined the effect of congruency of the previous trial (congruent/incongruent) on the current trial (congruent/incongruent). The trial-by-trial pattern observed was not in line with predictions derived from the conflict monitoring model. Davis et al. concluded that the congruency effect in recognition appears to hinge on enhanced processing of features on individual trials, and therefore may not be driven by the same mechanisms as congruency effects in online performance. This issue is a focus of Chapter 2 of this thesis.

Semantic Categories. Ortiz-Tudela et al. (2017) used a change detection task to study the influence of congruency involving semantic information on subsequent memory. A study trial consisted of two frames of a naturalistic visual scene that were flickered repeatedly, wherein one frame contained a target object and the other did not (Rensink et al., 1997). The participant detected and identified the target object that was changing across the frames, which was either congruent (e.g., a cow in a field) or incongruent (e.g., a cow in a street) with the scene. As predicted, target detection was faster on incongruent than congruent trials, presumably due to attention being captured by the salient incongruent target. In contrast, performance on a subsequent surprise recognition test for the targets alone was superior for formerly *congruent* than incongruent trials. These results run counter to those described previously (Krebs et al. 2015; Rosner, D'Angelo, et al. 2015) in that congruent trials were remembered better than incongruent trials. However, targets on congruent trials in this task, rather than targets on incongruent trials, may in fact require additional processing to detect because they do not "pop out" from the scene. The learning mechanisms at encoding may respond to this additional processing, leading to superior recognition for congruent over incongruent trials.

In a related study, Ptok et al. (2019) used a target-distractor procedure in a semantic categorization task. Participants categorized a target name on each trial as either male or female. The distractor word "male" or "female" was presented concurrently, and participants were told to ignore it. Critically, the distractor matched the correct response to the target name on congruent trials (e.g., “female” and “Kate”) and mismatched on incongruent trials (e.g., “male” and “Kate”). Categorization was slower on incongruent trials, and subsequent recognition was better for names on formerly incongruent than congruent trials. In a second experiment, the distractor words were changed to “left” and “right”. Because responses in the categorization task were predetermined (e.g., left-side key for female names and right-side key for male names), this task created congruent (e.g., “left” and “Kate”) and incongruent trials (e.g., “right” and “Kate”) based on response rather than meaning. Categorization was again slower on incongruent trials, but subsequent recognition was no different between the two trial types.

The response time results suggest that categorization on incongruent trials was effortful when interference occurred either at a semantic stage or at a response stage of processing. In line with this idea, pupil dilation during study was larger for incongruent than congruent trials in both variants of the task (Ptok et al., 2020). However, memory encoding was enhanced specifically when interference had a semantic basis, which presumably led to additional processing directed toward semantic level processing (i.e., is this name male or female?). In contrast, when interference had a response basis (i.e., “right” followed by a female name requiring a left response) additional processing would be directed toward resolving that response conflict, and no memory effect would be expected to occur (Ptok et al., 2019; Ptok et al., 2020).

Taken together, the studies of Ortiz-Tudela et al. (2017) and Ptok et al. (2019) make the important point that semantic congruency does have memory consequences, but not always in the form of a benefit for incongruent trials. In a change-detection procedure, targets on congruent trials were more difficult to process and better remembered. In a semantic categorization task, targets on incongruent trials were more difficult to process and better remembered. It appears that congruency—as one type of identification difficulty—can enhance memory if processing resources are consequently directed at semantic features of the target.

Spatial Expectation. Ortiz-Tudela et al. (2018) proposed that violation of expectation in a spatial cuing paradigm—a mismatch between cued location and target location—could have a comparable influence on subsequent recognition to spatial overlap of incongruent target and distractor (Krebs et al., 2015; Rosner, D'Angelo, et al., 2015). This proposal follows from the idea that a mismatch between expected and actual target location is a form of prediction error. Prediction error is proposed to trigger learning mechanisms that update representations for improved predictions in the future (Henson & Gagnepain, 2010). In their study, Ortiz-Tudela et al. (2018) examined whether spatial prediction errors enhanced performance in a subsequent verbal memory task.

In the study phase, participants were presented with an anticipatory visual cue that indicated the location at which a target word was likely to appear (for related methods, see Markant & Amso, 2014; Hauer & MacLeod, 2006). The cue was a centrally presented arrow and was either valid (i.e., it pointed to where the target subsequently appeared), invalid (i.e., it pointed to the location opposite to where the target subsequently appeared) or neutral (i.e., it was a row of lines that pointed to neither location). The incidental encoding task performed upon onset of the target was semantic categorization (natural/artificial) of the target word. A surprise recognition task followed in the test phase. Response times in the study phase demonstrated faster responses for cued targets than for uncued and neutral targets, but there was no difference in subsequent memory performance across the cued, uncued, and neutral conditions.

The same pattern was observed when the encoding task was changed from semantic categorization to simple word naming, and when the cue was changed from a centrally presented arrow (endogenous cue) to a peripheral row of asterisks (exogenous cue). These results ruled out notions that particularly deep encoding on cued trials due to either semantic judgments (Craik & Lockhart, 1972) or endogenous cuing (Hauer & MacLeod, 2006) countered a benefit for uncued targets due to prediction error. All told, across seven experiments, the results strongly favoured the null hypothesis, that there was no difference in recognition for cued and uncued targets.

These results suggest that a mismatch in spatial expectation due to an invalid spatial cue involves mechanisms separate from those that drive congruency effects in recognition due to an incongruent distractor. An important difference in method between these two types of study is that the spatial cuing paradigm produces a spatial expectation mismatch but no mismatch in processing related to target identity (Ortiz-Tudela et al., 2018). In effect, the invalid spatial cue may well have interfered with target localization, but not with processing of the target identity itself, with a mismatch in identity being critical to observe an effect in subsequent memory.

Repetition

Perceptual identification difficulty also varies as a function of stimulus repetition. In most contexts, repetition affords an advantage to identification (e.g., Jacoby & Dallas, 1981). However, if perceptual identification difficulty is positively associated with long-term retention, then there ought to be some way to demonstrate improved long-term retention for not-repeated events relative to repeated events. Of course, a challenge that makes this outcome seem unlikely is the vast number of studies indicating that repetition supports learning and memory (Greene, 1989; Hintzman, 1976; but see Mulligan & Peterson, 2013).

This challenge was met with a method that reliably demonstrates superior memory for not-repeated relative to repeated items (Rosner, et al., 2018). In an incidental study phase, Rosner et al. presented a prime word that was immediately followed by a target word on each trial; participants were to name the target word aloud. The prime and target words had the same identity on repeated trials, and different identities on not-repeated trials. Naming times were faster on repeated trials, reflecting a typical repetition priming effect. In contrast, performance on a subsequent recognition task was better for targets on formerly not-repeated trials.

This repetition decrement effect in recognition hinges on inattention to the prime (Collins, et al., 2018; Experiment 4, Rosner et al., 2018). When participants name both the prime and target words, or when they attend to the semantic features of the prime word, memory performance reverses to benefit for repeated trials over not-repeated trials (Collins et al., 2018; Rosner et al., 2018). These findings suggest that when participants can remember the prime from a prime-target pair, subsequent recognition for repeated targets benefits from repetition. In contrast, when the method makes recognition of primes from prime-target pairs difficult, stimulus repetition can be shown to impair recognition.

Increases in the temporal spacing between prime and target also mediate this effect. Whereas immediate prime-target repetition under the conditions described above reliably produces a repetition decrement effect, a 10-minute spaced interval between repetitions produces the more customary repetition benefit (Collins & Milliken, 2019). This result supports the idea that the processes driving the repetition decrement may be similar to those that produce poorer memory for repeated items that are spaced close together than for repeated items that are spaced further apart—the well-known spacing effect in the memory literature (Bjork & Allan, 1970; Cuddy & Jacoby, 1982).

The fact that recognition is poor for the items that were processed most easily at study begs an answer to how the repetition decrement is related to perceptual fluency heuristics known to influence memory judgments (e.g., Jacoby & Whitehouse, 1989). This issue was addressed by examining both the repetition decrement effect (produced by repetition at study) and perceptual fluency induced false recognition (produced by repetition at test) in the same experiment (Rosner & Milliken, *under revision*). In short, both effects can be observed in the same experiment, but they appear to have different underlying bases. False recognition effects driven by perceptual fluency tend to be observed in the fastest of recognition responses, whereas the repetition decrement effect is driven by information retrieved more slowly and therefore appears in the slower recognition responses. These results suggest strongly that the repetition decrement effect has a conceptual rather than perceptual basis (see Boldini et al., 2004; Parks, 2013).

Orthography

Perceptual identification difficulty of verbal stimuli varies as a function of orthographic distinctiveness. The orthographic distinctiveness effect describes the result of better memory for words with unusual orthography than words with common orthography (Zechmeister, 1969; 1972; Hunt & Mitchell, 1978; Hunt & Elliot, 1980; Hunt & Toth, 1990). This effect drew theoretical attention in part because perceptual features were widely considered transient representations, with minimal contributions to long term-memory (Hunt & Elliot, 1980). Yet this data-driven, perceptual manipulation of orthography revealed robust differences in memory performance on conceptual tasks, such as free recall, recognition, and word fragment cued recall.

Orthographically distinct words are thought to attract attention and additional processing to their visual features, which in turn leads to greater conceptual processing of the items relative to their orthographically common counterparts (Hunt & Elliot, 1980; Garaci & Rajaram, 2002). The critical property of words that produces the orthographic distinctiveness effect is indeed visual distinctiveness and not unusual letter combinations. This conclusion is supported by the findings that both auditory presentation and capitalization of visual letters, which both maintain unusual letter combinations but minimize visual distinctiveness, eliminate the orthographic distinctiveness effect in recall (Hunt & Elliot, 1980; McDaniel et al., 2015). Support for greater conceptual processing underlying this effect comes from studies that used words with low meaningfulness (Hunt

& Elliot, 1980) and implemented a divided attention requirement at study (Geraci & Rajaram, 2002), both manipulations that limit conceptual processing. Here, the memory benefit for orthographically distinct words was eliminated or reduced[1].

The conceptual representations enhanced by distinct orthography were demonstrated to be item-specific rather than relational in nature (Hunt & Einstein, 1981; Hunt & McDaniel, 1993); that is, features unique to the orthographically distinct word itself rather than those that relate that orthographically distinct word to others in the study list appear to underlie the effect (Hunt & Elliot, 1980; Hunt & Mitchell, 1982; McDaniel et al., 2011; 2015). In addition, the orthographic distinctiveness effect is only observed in memory tasks that load on conscious remembering (Geraci & Rajaram, 2002; see also Hunt & Toth, 1990). In explicit memory tasks such as free recall, recognition, and word fragment cued recall, performance is better for words with distinct than common orthography. In contrast, implicit memory tasks such as perceptual identification (Hunt & Toth, 1990) and word fragment completion (Geraci & Rajaram, 2002) do not produce an orthographic distinctiveness effect. The temporal task demands of perceptual identification may not be conducive to retrieving the complex patterns of orthographically distinct words from memory (Hunt & Toth, 1990)[2].

[1] Interestingly, an orthographic distinctiveness benefit for words with low meaningfulness was observed in a recognition task, which contrasts with the null effect observed in free recall (Hunt & Elliot, 1980). Distinct orthography may still aid in discrimination, even though reconstruction is hindered by low semantic accessibility.

[2] Hunt & Toth (1990) did in fact observe an orthographic distinctiveness effect in a word fragment completion task, but Geraci and Rajaram (2002) demonstrated that this was likely due to contamination of conscious strategies by participants who were aware of the relation between the study and test phases.

Theoretical Evaluation of Perceptual Identification Difficulty Effects on Long-term Retention

The previous section summarized five classes of effects that fall under the umbrella of perceptual identification difficulty effects on subsequent retention. In this section, I discuss theoretical frameworks that may be used to explain why these effects occur. The goal is to examine the summarized difficulty effects together in the context of each framework to evaluate how well that framework handles the full range of effects.

Distinctiveness

Hunt (2006) provided a comprehensive description of how distinctive processing ought to be conceptualized in memory research. Namely, certain experimental manipulations implemented at the time of study promote unique processing of particular items relative to other items, which in turn enhances the discriminability of those uniquely encoded items at retrieval. This relatively straightforward idea has substantial explanatory power, and has become a popular candidate framework for understanding numerous memory effects. One notable example is the bizarreness effect—better memory for items used to generate bizarre imagery than non-bizarre imagery (McDaniel & Einstein, 1986). A second example is the production effect—better memory for words read aloud than read silently (MacLeod et al., 2010; Hopkins & Edwards, 1972).

One tenet of distinctiveness accounts of memory phenomena is that distinctiveness of an item is defined relative to other items. In other words, the memory benefit for a distinctively processed item depends on it contrasting with other study items. Hunt (2006) phrased this idea most appropriately: "[distinctiveness is] the processing of difference in the context of similarity" (pg. 12). A simple but effective test of relative distinctiveness is to compare memory performance across mixed and pure lists. In a mixed list, both the common and unusual (or difficult) item types are presented in the same context, creating a clear contrast in processing demands between them. This is a context wherein difference is processed in the context of similarity. In contrast, pure lists involve the presentation of item types in separate list contexts. Here, unusual items are not presented among common items, eliminating the backdrop of common items from which the unusual items can be processed differently. A distinctiveness account therefore predicts that a memory benefit for unusual item types would be observed in mixed lists but not in pure lists. In line with this prediction, both the bizarreness effect and the production effect in free recall are observed in mixed lists but not as reliably in pure lists (McDaniel & Einstein, 1986; Jonker et al., 2014).

Although the story seems clear to this point, it is made somewhat more complex when considering the effects of the memory task. While memory benefits for unusual items have been found exclusively in mixed lists in free recall tasks, several such effects have been found in both mixed and pure lists in recognition (Fawcett, 2013; for a review see McDaniel & Bugg, 2008). The observation that the memory benefit for unusual items can survive a pure list manipulation suggests a process other than, or in addition to, distinctiveness is at play. In addition, the dependence of the mixed versus pure-list dissociation on the type of memory test used (recall or recognition) points to processes active at the time of retrieval as an important factor, rather than those at the time of encoding alone (McDaniel & Bugg, 2008).

Evaluation. With regard to the memory effects summarized in the previous section, the results to date indicate that many of them can be found in both mixed and pure or blocked lists in recognition: visual blur (Rosner et al., 2015); congruency (Davis et al., 2020; see Chapter 2); distinct orthography (McDaniel et al., 2011); perceptual interference (Mulligan, 1999). This reliable pattern is not in line with a distinctiveness account of these effects (Hunt, 2006).

Another challenge concerns how the definition of distinctiveness is applied in the semantic congruency effect reported in a change detection task (Ortiz-Tudela, et al., 2017). As discussed previously, incongruent targets were more easily detected in the change detection task itself, but congruent targets were better remembered on a subsequent recognition test. Here, it seems reasonable to conclude that incongruent targets were more distinctive, because they mismatched the surrounding scene. At the same time, congruent targets could well have been more distinctive because their relative difficulty promoted unique processing during the change detection task, which in turn enhanced memory encoding. Even given the relatively clear definition prescribed by Hunt (2006), we are left with an unclear a priori sense of which condition ought to be considered to have higher distinctiveness.

Given this lack of definitional specificity, and the empirical findings that appear inconsistent with the distinctiveness account, I conclude that the construct of distinctiveness falls short of a full account of the difficulty effects considered here.

Item-Relational Processing

The item versus relational processing distinction has played an important role in the memory literature (Hunt & Einstein, 1981; Hunt & McDaniel, 1993). Item-specific information consists of features that are unique to each item, while relational information describes features that are shared across multiple items in a list. Both types of information can be encoded, and can differentially contribute to performance at retrieval. In a seminal demonstration, orienting tasks that promote relational processing (semantic categorization) on the one hand, and item processing (pleasantness ratings) on the other hand, made unique contributions to retrieval—completing both types of orienting tasks led to superior recall over completing either type of orienting task twice (Hunt & Einstein, 1981; see also McDaniel et al., 1988).

A recent variant of the item-relational framework is the item-order account (McDaniel & Bugg, 2008). This account offers additional predictions for memory performance, specifically those involving a trade-off between item and order processing at encoding (order being a subtype of relational information). Certain encoding manipulations are thought to promote the preferential encoding of one type of information over the other. This qualitative difference in encoding can be observed in subsequent memory performance, depending on the retrieval demands of the memory task. Specifically, certain encoding manipulations are assumed to enhance the encoding of item-specific information at the expense of order information. McDaniel and Bugg (2008) reviewed five well-known memory effects, including the bizarreness and perceptual interference effects. A memory benefit for the difficult to process item type was found in both mixed and pure lists in recognition, but only in mixed lists in free recall.

This dissociation is well accounted for by the item-order account by focusing on the interaction between (1) the differential processing of item and relational information at encoding and (2) the differential utility of item and relational information at retrieval. A central assumption is that unusual/difficult to process items promote item-specific encoding regardless of study context, whereas common/easy to process items mainly promote the encoding of order information. In a mixed list, the enhanced item-encoding on unusual/difficult trials disrupts the encoding of order information for both the easy and difficult trials. In a blocked or pure list, unusual/difficult items are still preferentially encoded via item processing, whereas common/easy items allow additional order processing. The key issue here is that presenting the two item types in separate list contexts is critical to the encoding of order for the common/easy items. At test, the relative strengths in item and order memory are expressed differently depending on the memory task. Relational information is useful for generating potential responses from memory, whereas item-specific information contains useful discriminative features. Recognition is therefore widely considered to promote a reliance on item-specific information to guide retrieval, whereas recall allows reliance on both types of information (Hunt & Einstein, 1981; McDaniel & Bugg, 2008). Because recognition relies primarily on item information, a memory benefit for unusual/difficult items is observed regardless of encoding context (mixed or pure lists). In contrast, both enhanced item information for unusual/difficult items and order information for common/easy items can be utilized in free recall. However, the encoding of order information is disrupted in mixed lists, and intact in pure lists. Therefore, a memory benefit for unusual/difficult items is observed in mixed lists but not in pure lists.

McDaniel and Bugg (2008) describe how several well-known memory effects, including the bizarreness effect, align with this prediction. Moreover, they note the utility of other predictions of the framework, such as that there should be worse performance on relational measures (e.g., order reconstruction, input-output correspondence, clustering) for unusual/difficult than common/easy items when items are presented in pure lists, and equivalent performance on relational measures between easy and difficult items when items are presented in mixed lists. Jonker and colleagues have demonstrated recently that the production effect (Jonker et al., 2014; see also Jonker & MacLeod, 2015; 2017) produces results that align well with this framework.

Evaluation. How does the item-relational framework described above fare in explaining the perceptual difficulty effects focused on here? More specifically, does perceptual processing difficulty promote item-specific encoding, possibly to the detriment of relational encoding, and does that enhanced item-specific encoding explain perceptual difficulty effects on subsequent retention?

With respect to the perceptual interference effect, the compensatory processing account does assume that processing adjustments at the time of encoding produce superior memory performance for pattern masked items than for unmasked items (Hirshman et al., 1994). Mulligan (1999) proposed further that the higher-order representations enhanced by pattern masking are item-specific in nature, which aligns well with the item-relational account. Moreover, Mulligan (1999) noted several specific predictions of the item-relational distinction that fit well with the way that the perceptual interference effect varies as a function of memory task. For example, with both categorized and uncategorized word lists, recall is superior for masked words than for unmasked words. However, category clustering scores revealed the opposite pattern, with higher scores for the unmasked words than for the masked words. Similarly, performance on an order reconstruction task was better for unmasked than masked words when the masking manipulation was blocked. Other experiments indicate that the perceptual interference effect is more robust in recognition than in free recall (Mulligan, 1999; see also Nairne, 1988; Hirshman & Mulligan 1991). All told, the compensatory processing account used to explain the perceptual interference effect fits well with the item-relational framework: Processing difficulty produced by pattern masking results in enhanced item-specific, higher-order semantic encoding that subsequently facilitates memory performance in tasks that depend on that type of encoding.

The item-relational framework has also been used to describe the enhanced conceptual processing presumed to underlie the orthographic distinctiveness effect. Several findings in the orthographic distinctiveness literature are in line with the predictions derived from this framework (McDaniel et al., 2011; 2015). First, an orthographic distinctiveness effect is observed in both mixed and pure lists in recognition, but the effect is isolated to mixed lists in free recall (Hunt & Elliot, 1980; McDaniel et al., 2015). Second, measures of order memory including input-output correspondence, order reconstruction, and clustering, are worse for orthographically distinct words than orthographically common words (Hunt & Mitchell, 1982; McDaniel et al., 2011; 2015). Third, orthographically distinct words exhibit worse recall and lower clustering compared to orthographically common words in categorized lists, suggesting that participants are less able to take advantage of categorical structure to guide retrieval (McDaniel et al., 2015). When participants are provided with the category labels at test, clustering scores are equivalent but recall is still worse for orthographically distinct words, suggesting that distinct orthography hinders relational processing specifically at encoding. These results are consistent with the view that processing of orthographically distinct words enhances the encoding of item information but impedes that of relational information, including categorical information in structured lists. Put in broader terms, processing of distinct non-semantic (orthographic) features may be thought to promote semantic processing of items but to impede processing of semantic features shared across items.

There is some evidence that the item-relational framework also fits with findings from studies of the congruency effect with spatially interleaved words (Rosner, D'Angelo, et al., 2015). This effect is observed with both mixed and blocked study lists in recognition, and shows little dependence on local trial-to-trial sequences during the study phase (Davis et al., 2020, see Chapter 2). These results point to an influence on encoding of the item itself over the context in which an item appears.

Although additional study is needed on this topic, the perceptual degradation effect using visual blur also appears to occur for both mixed and blocked lists in recognition (Rosner et al., 2015), and therefore aligns with the item-relational framework. The available data from studies of semantic congruency effects (Ortiz-Tudela, et al., 2017; Ptok et al., 2019), spatial cuing effects (or its lack thereof; Ortiz-Tudela et al., 2018), and repetition effects (Rosner et al., 2018; Collins et al., 2018) are currently insufficient to evaluate the item-relational framework.

Taken together, I conclude that the item-relational framework holds promise for accounting for the effects reviewed in the previous section. More research to better ascertain its fit with some of the effects would be worthwhile.

Conflict Monitoring

The item-relational framework seems like a strong candidate for understanding perceptual difficulty effects in subsequent retention. However, this framework is not specific about how perceptual processing difficulty produces adjustments in processing that favour item-specific encoding. One place to look for an answer to this question is in the cognitive control literature. Cognitive control refers to a set of mechanisms that coordinate adjustments in cognition and behaviour to enhance the processing of task-relevant information. Of interest here, there has been an increase in interest in how transient, online adjustments in control may influence learning and memory (Krebs et al., 2015; Ptok et al., 2019; Rosner et al., 2015; Verguts & Notebaert, 2009), with a particular focus on the conflict monitoring model.

The conflict monitoring model proposes that cognitive control is modulated by processes that are sensitive to conflict in online information processing, specifically at the level of response selection (Botvinick et al., 2001). When task-irrelevant information activates representations that are at odds with those activated by task-relevant information, the anterior cingulate cortex (ACC) generates a conflict signal that is received by the dorsal lateral prefrontal cortex (dlPFC). The dlPFC then orients attentional control toward processing of task-relevant information, thereby resolving the conflict and guiding response selection to that information. This model has been influential in accounting for behaviour in many online performance tasks such as Stroop, Simon, and flanker (for a review see Botvinick et al., 2001; Carter & van Veen, 2007).

Subsequent discussions proposed that these adjustments in control due to response conflict may have learning consequences (Botvinick, 2007; Verguts & Notebaert, 2008; 2009). Verguts and Notebaert proposed a learning account of cognitive control, in which the locus coeruleus (LC) acts as an intermediary between the ACC and dlPFC. The LC triggers the release of norepinephrine upon detection of conflict by the ACC, which in turn facilitates online learning and binding of task-relevant information (for an alternative theory on LC function see Aston-Jones & Cohen, 2005). By this view, stimulus-response information encountered on conflict trials should benefit from LC-modulated enhancements in encoding relative to no-conflict trials. This account is most readily linked to the congruency effects discussed earlier. For both picture-word Stroop-like stimuli (Krebs et al., 2015) and spatially interleaved word stimuli (Rosner, D'Angelo, et al., 2015), recognition was superior for targets formerly paired with incongruent as opposed to congruent distractors.

More recent work derived from the original conflict monitoring model has explored signals for control adaptation other than response conflict. The expected value of control account (Shenhav et al., 2013) posits that the dACC is responsible for general monitoring and control-signal implementation. The dACC does so by engaging in an ongoing cost-benefit analysis. This analysis compares the expected value of control (EVC) for several candidate control signals, taking into account the potential reward of upregulating control against the inherent energetic cost of this upregulation. The output of this analysis is a specification of the identity and intensity of the signal with the highest EVC (i.e., the optimal control signal to maximize reward).

This EVC framework encompasses the original proposal that the dACC is sensitive to response conflict (Botvinick et al., 2001), but response conflict is nested within a broader discussion of task difficulty (Shenhav et al., 2013). Task difficulty is proposed to increase the EVC across candidate control signals, and therefore also increases the likelihood of cognitive control adaption in response to task difficulty. For the five classes of memory effects discussed here, this extension of conflict monitoring theory holds some promise as the only one of the five classes of effects that is centered on overt “conflict” between relevant targets and irrelevant distractors. Rather, the EVC framework allows for broad adaptations in cognitive control in response to processing difficulty that could conceivably have memory consequences.

Evaluation. Krebs et al. (2015) and Rosner, D’Angelo, et al. (2015) first proposed a potential link between upregulations in control due to conflict and subsequent memory. The basic idea was that response conflict between target and distractor items on incongruent trials should trigger an upregulation in cognitive control, and the enhanced attentional processing that follows should in turn enhance encoding and subsequent memory. Results from these two studies did provide preliminary evidence in support of this idea. The EVC framework allows one to extend this general idea to a broader range of tasks in which perceptual difficultly at encoding is manipulated. However, beyond a general encoding enhancement on certain trials as a consequence of conflict (or difficulty more generally), these frameworks do not specify how transient shifts in control influence particular memory representations at encoding. As a result, they also fall short of making precise predictions for diverse memory tasks that vary in their retrieval demands. Of course, this is a strength of the item-relational framework, so perhaps what is now needed is research that blends the strengths of item-relational and conflict monitoring frameworks (see Chapter 4 of this thesis for some initial work on this issue).

A more serious concern with application of the conflict monitoring framework to the memory effects focused on here is preliminary results that fail to align with this framework. Davis et al. (2020, see Chapter 2 of this thesis) generated predictions for memory performance based on the conflict monitoring model, both for effects of list context and for sequential trial effects. Note that effects of list context and trial sequence in tasks such as Stroop (Stroop, 1935) and flanker (Eriksen & Eriksen, 1974) are well captured by the conflict monitoring model (for a review see Bugg & Crump, 2012; Carter & van Veen, 2007; Egner, 2007). Yet, the magnitude of the congruency effect in subsequent recognition was insensitive to two manipulations of list context: proportion congruency and mixed/blocked lists. Davis et al. (2020) also conducted a re-analysis of all available data, and failed to observe sequential effects in memory performance that are in line with the conflict monitoring model. The processes that underlie the congruency effect in recognition may not be the same as those driving congruency effects in online performance as profiled by the conflict monitoring model.

An additional challenge is highlighted by the change-detection task results of Ortiz-Tudela et al. (2017). Recall that they observed more efficient change detection for targets when the surrounding scene was semantically incongruent than when the surrounding scene was congruent. For change detection, congruent trials rather than incongruent trials were the more difficult trial type. In turn, subsequent memory performance was better for formerly congruent than incongruent targets. This result demonstrates that incongruency per se (between target identity and scene context in this case) does not obligatorily enhance memory encoding. Rather, in line with the EVC framework (Shenhav et al. 2013), broader processing difficulties could lead to control adaptations that influence memory encoding.

The EVC framework could in principle be extended to any of the other perceptual difficulty effects discussed here. Better memory for blurry than clear words (Rosner et al., 2015), for distinctive than common orthographies (McDaniel et al., 2011; 2015), for not-repeated than repeated words (Rosner et al., 2018; Collins et al., 2018), and for pattern masked than for unmasked words (Hirshman et al., 1994; Mulligan, 1999), could all be consequences of a cost-benefit analysis of the value of upregulated cognitive control. That said, a careful examination of stimulus features and task demands at encoding (and at retrieval) will be needed for the EVC framework to fulfill its promise.

Stage-Specific Control

The previous section pointed out a salient shortcoming of the conflict monitoring model—that upregulated cognitive control in response to encoding difficulty is not sufficiently specific in this model to capture when encoding difficulty does and does not improve subsequent memory. Some recent work on a stage-specific control account aims to address this issue. (Ptok et al., 2019; Ptok et al., 2020; Ptok & Watter, *under revision*).

The central tenet of the stage-specific control account is that the particular stage of processing that is modulated by a difficulty manipulation determines whether a subsequent memory effect is observed. Ptok et al. (2019) first examined this account by comparing semantic versus response interference effects on subsequent recognition. They proposed that a difficulty manipulation that targets the semantic recognition/categorization stage of processing will cause attention to be directed toward the conceptual features of the target item. This attention to conceptual features should result in better remembering of difficult than easy to process items. Indeed, when participants completed a gender-name categorization task, where on some trials the target name and distractor gender were congruent ("Kate" – "female") and on others they were incongruent ("Kate" – "male"), subsequent recognition was better for names on formerly incongruent trials. These results suggest that the semantic conflict encountered between the identity of the distractor and the correct response to the target on incongruent trials promoted additional conceptual processing of the target.

In contrast, if a difficulty manipulation directs processing toward the response selection stage, attention is shifted away from the target's conceptual features. On a conceptually-driven memory test like recognition, the result is equivalent performance for difficult and easy to process items. Indeed, when participants were pre-assigned response mappings based on gender (e.g., left-side key for female names and right-side key for male names) and presented with target names together with the words "left" or "right" as distractors, recognition performance was no different between congruent trials (e.g., "Kate" – "left") and incongruent trials (e.g., "Kate" – "right"). Here, the response conflict encountered on incongruent trials directed attention toward response selection rather than semantic processing of the name, thereby conferring no recognition benefit for incongruent trials.

These results demonstrate that processing difficulty does not always enhance subsequent memory. Rather, it does so only when the source of difficulty is a stage toward which attention amplifies processes that are later tapped by the memory task. In this case, the memory task was a conceptually-driven recognition task, and therefore attention to semantic information, but not to response information, was critical to improving subsequent memory. It is in this sense that conflict as discussed in the conflict monitoring literature may be conceptualized too generally for the purpose of understanding processing difficulty effects on memory encoding (Ptok et al., 2019; see also Ptok et al., 2020; Ptok & Watter, *under revision*).

Evaluation. The stage-specific control account layers nicely onto well-established conflict-monitoring frameworks, and offers a more specific set of predictions about when conflict will and will not influence subsequent memory. Whereas both response conflict and semantic conflict result in cognitive control adaptations, only the adaptations triggered by semantic conflict are predicted to improve subsequent memory. It is worth noting that the ACC, the region widely assumed to trigger adaptations in cognitive control, is activated in both perceptual and semantic conflict tasks (van Veen & Carter, 2005; Weissman et al., 2003).

Although much additional data are needed to evaluate the stage-specific control account, the prominent role of semantic processing in this account is noteworthy. The idea that interference at encoding must target the semantic representation stage to confer a benefit to subsequent memory echoes other accounts of processing difficulty effects on memory. For instance, the compensatory processing account for the perceptual interference effect (Hirshman et al., 1994) posits that disruption of visual information by a pattern mask promotes additional post-perceptual processing of the word. The item-relational framework highlights the importance of conceptual information specific to a particular item in producing benefits in subsequent memory. Theoretical accounts of the orthographic distinctiveness effect (McDaniel et al., 2011; 2015) also point to the importance of increased attention to semantic features for orthographically distinct items. Lastly, the null effects reported by Ortiz-Tudela et al. (2018) also highlight the importance of attention to semantic information in producing benefits in subsequent memory. In that study, the difficulty manipulation at encoding involved validity of spatial cues relative to target location. Although target localization was clearly more challenging on invalid trials, it seems likely that processing of the semantic target features post-localization was not. As a result, difficulty in orienting attention toward the target location on invalid trials may have had little impact on semantic processing of the targets themselves. Therefore, no benefit in subsequent recognition would be expected.

Event Segmentation

Event segmentation theory proposes that people perceive continuous experience as a series of discrete events, wherein an event is a chunk of time in a given context that is considered as having a beginning and an end (Kurby & Zacks, 2008; Zacks et al., 2007; Zacks & Swallow, 2007; Zacks & Tversky, 2001; see also Ezzyat & Davachi, 2011). This spontaneous segmenting of experience into events is thought to be a side effect of trying to anticipate future information. As we perceive an experience, sensory information is transformed into multimodal representations that are coupled with semantic context. This perceptual processing is guided by event models, which are online representations of what is currently happening in the environment. Our perceptual systems continuously generate predictions of future input based on event models, and the quality of the predictions is monitored by an error detection mechanism. Prediction error increases when the active event model no longer fits with current input, which in turn increases the system's sensitivity to sensory input and the event model is updated. This transient increase in prediction error and the updating of memory is perceived by the observer as the end of one event and the beginning of another.

A key long-term memory implication of event segmentation centers on processing at event boundaries. Transient increases in prediction error at boundaries may act as a signal to upregulate control, which increases sensitivity to sensory information at the point when a new event model is being created. This sensitivity to sensory input leads to enhanced processing and encoding of information at boundaries (Kurby & Zacks, 2008; Zacks et al., 2007; Zacks & Swallow, 2007). Indeed, memory for objects presented at what were later identified as event boundaries is superior to memory for other objects (Swallow et al., 2009; see also Boltz, 1992; Newtson & Engquist, 1976; Schwan et al., 2000).

Evaluation. Turning to the memory effects under examination, perhaps perceptual identification difficulties at encoding coincide with prediction error, which then acts as a catalyst to segment events. Difficult to process items, then, may tend to reside at event boundaries in memory. Given the theoretical tenet that event boundaries scaffold memory encoding, it is easiest to conceptualize these effects by considering encoding of mixed study lists. When easy and difficult to process items are intermixed, the difficult items may trigger an increase in prediction error while the easy items would not. This increase in prediction error for difficult items may lead to the creation of an event boundary, whereas the lower prediction error for easy items would lower the likelihood of them being encoded at an event boundary. In blocked lists, however, difficult items are only encountered in the context of other difficult items. Would each trial then create a new event boundary? Whether this is a reasonable proposal is an important issue to address in subsequent research. Note that the effects of visual blur (Rosner et al., 2015), congruency via spatial overlap (Davis et al., 2020, see Chapter 2), perceptual interference (Mulligan, 1999), and distinct orthography (McDaniel et al., 2011) are all observed in blocked or pure lists in recognition.

Discussion

The goal of the Introduction to the thesis was to examine the association between perceptual identification difficulties and long-term retention, and to set the context for the empirical work in the thesis. To this end, I provided an overview of five classes of empirical effects that fit the idea that increased processing difficulty can improve subsequent memory performance. Next, I evaluated several theoretical accounts from the memory and cognitive control literatures that may be used to explain these effects. The empirical work that follows focuses on one of the memory effects described in the Introduction: the congruency effect with spatially overlapping words.

Chapter 2 of the thesis demonstrates limitations of the conflict monitoring model of cognitive control (Botvinick et al., 2001) as it applies to memory processes that underlie the congruency effect (Davis et al., 2020). Specifically, the empirical work in this chapter demonstrates that this effect is relatively insensitive to list context, and that interleaving of words (regardless of their congruency) introduces perceptual interference that improves memory performance.

Chapter 3 of this thesis confirms that the congruency effect is influenced by factors in addition to perceptual interference from the interleaving manipulation (Davis & Milliken, *in prep*). In line with much evidence covered in the Introduction, semantic interference appears to play an important role in the upregulated learning that drives the congruency effect.

Chapter 4 demonstrates a congruency effect in free recall for the first time (Davis & Milliken, *under revision*). However, the effect is more robust in recognition, aligning the pattern of results with the item-relational framework outlined in the Introduction.

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Chapter 2

Selective attention effects on recognition:

The roles of list context and perceptual difficulty

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Abstract

Two recent studies reported superior recognition memory for items that were incongruent targets than for items that were congruent targets in a prior incidental study phase (Krebs, Boehler, de Belder, & Egner, 2013; Rosner, D'Angelo, MacLellan, & Milliken, 2015). The present study examined this effect further by addressing two issues. First, we examined whether this effect is sensitive to the list context in which congruent and incongruent items are presented. In Experiment 1, this issue was addressed by manipulating the relative proportions of congruent and incongruent trials in the study phase. In Experiments 2A and 2B, the same issue was examined by contrasting randomly intermixed and blocked manipulations of congruency. The results of these experiments, as well as a trial-to-trial sequence analysis, demonstrate that the recognition advantage for incongruent over congruent items is robust and remarkably insensitive to list context. Second, we examined recognition of incongruent and congruent items relative to a single word baseline condition. Incongruent (Experiment 3A) and congruent (Experiment 3B) items were both better recognized than single word items, although this effect was substantially stronger for incongruent items. These results suggest that perceptual processing difficulty, rather than response conflict on its own, contributes to the enhanced recognition of incongruent items. Together, the results demonstrate that processes that are sensitive to perceptual processing difficulty of items but largely insensitive to list context produce heightened recognition sensitivity for incongruent targets.

Introduction

Cognitive control refers to processes that direct thought and behaviour toward goal-relevant sources of information. Although cognitive control plays a central role in the study of both remembering (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Jacoby, 1991) and selective attention (Eriksen & Eriksen, 1974; Simon, 1969; Stroop, 1935), these two domains of study have remained largely separate. However, there is emerging interest in the idea that cognitive control processes that support selective attention may also contribute to memory encoding. In particular, two recent studies have reported superior recognition of "conflict" items—targets encoded in the context of incongruent distractors were recognized better than targets encoded in the context of congruent distractors (Krebs, Boehler, de Belder, & Egner, 2013; Rosner, D'Angelo, MacLellan, & Milliken, 2015).

Selective Attention and Recognition Memory

Krebs et al. (2013) examined recognition memory for stimuli studied in the context of a face-word Stroop-like task. During the study phase, participants completed a gender discrimination task for images of male or female faces. The word "man", "woman", or "house" was superimposed on each face, creating congruent (i.e., the word "man" superimposed on a male face), incongruent (i.e., the word "woman" superimposed on a male face), and neutral items (i.e., the word "house" superimposed on a male face). Response times (RTs) were slower for incongruent than congruent trials, reflecting the typical behavioural effect observed in Stroop tasks. More important, performance in a later surprise recognition memory task was better for faces that had been presented in incongruent study phase trials than for faces presented in congruent or neutral trials. Krebs et al. also measured the BOLD response that indirectly reflects neural activity using fMRI, and found that the memorial benefit for incongruent items was associated with activity in the dorsolateral prefrontal cortex (dlPFC)—a brain region known to be critical for implementing cognitive control (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, 2007).

In a conceptually similar study, Rosner, D'Angelo et al. (2015) presented participants with two spatially interleaved words, a red target and a green distractor, on each trial of an incidental study phase. The two words had either the same identity (congruent trials) or different identities (incongruent trials). The task during the study phase was to read aloud the red target word and ignore the green distractor word. As expected, RTs were faster for congruent trials than for incongruent trials. In a later surprise recognition memory test, memory was better for words that had been targets on incongruent trials than for words that had been targets on congruent trials in the study phase.

These two studies confirm that congruency, as defined in studies of selective attention, can indeed influence recognition memory. The present manuscript addresses two key empirical issues related to this effect. First, a well-documented property of congruency effects in selective attention studies is their sensitivity to list context (Gratton, Coles, & Donchin, 1992). If congruency effects in recognition are driven by the same processes as congruency effects in studies of selective attention, then the congruency effect in recognition also ought to be sensitive to list context. Second, although superior recognition for incongruent items in prior studies has been attributed to response conflict (Krebs et al., 2013; Rosner, D'Angelo et al., 2015), incongruent items may also differ from congruent items in overall perceptual processing difficulty. These two issues were examined in a series of five experiments. Prior to describing these experiments, a brief review of the role of list context in studies of selective attention is provided.

Selective Attention and List Context

A key finding in the literature on selective attention is that congruency effects are sensitive to the list context in which items are encountered. For example, in many selective attention tasks (e.g., Stroop, flanker), congruency effects are larger for blocks of trials with a high proportion of congruent items than for blocks of trials with a low proportion of congruent items (Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; for a review, see Bugg & Crump, 2012). This result suggests that a high proportion of congruent items within a block increases the likelihood that participants are ill-prepared to filter distractors when an incongruent trial is encountered. A related finding focuses more directly on trial-to-trial influences on congruency effects (Botvinick et al., 2001; Egner & Hirsch, 2005; Kerns et al., 2004; Kerns, 2006; Verguts & Notebaert, 2008; for a review see Carter & van Veen, 2007; Egner, 2007). Gratton et al. (1992) first reported that flanker compatibility effects are smaller following incompatible (incongruent) trials than following compatible (congruent) trials. This finding is often referred to as a sequential congruency effect. Sequential congruency effects have also been observed reliably in many tasks, including Stroop (Kerns et al., 2004), Simon (Kerns, 2006; Strümer, Leuthold, Soetens, Schröter, & Sommer, 2002), and Eriksen flanker (Ullsperger, Bylsma, & Botvinick, 2005; Verbruggen, Notebaert, Liefooghe, & Vandierendonck, 2006). As with proportion congruent effects, sequential congruency effects imply that list context influences whether participants are prepared to filter distractors on incongruent trials, which in turn influences the magnitude of congruency effects.

The robust influence of list context in on-line performance studies of selective attention raises a straightforward issue of relevance for studies of congruency effects in recognition memory: Are congruency effects in recognition sensitive to the same contextual factors as congruency effects in on-line performance studies of selective attention? This issue was examined in Experiments 1, 2A, and 2B of the present study.

To describe how list context effects in on-line performance might translate to list context effects in recognition, we make use of the conflict monitoring model of cognitive control (Botvinick et al., 2001). According to the conflict monitoring model, proportion congruent and sequential congruency effects result from transient adaptations in cognitive control. Generally speaking, congruent trials result in a down-regulation of cognitive control while incongruent trials result in an up-regulation of cognitive control. Up-regulation of cognitive control on an incongruent trial leaves participants well prepared to filter distractors on the following trial, whereas down-regulation of cognitive control leaves participants poorly prepared to do so (Botvinick et al., 2001; but for an alternative interpretation of sequential congruency effects, see Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003). These transient adaptations in cognitive control produce particularly slow RTs for incongruent trials that follow congruent trials (c-I trials), as participants are poorly prepared to filter distractors in this type of trial transition. In contrast, distractor interference slows performance less for incongruent trials that follow incongruent trials (i-I trials), as participants are better prepared to filter distractors in this type of trial transition. Together, these two types of trial transition contribute to the smaller congruency effects typically observed following incongruent trials than following congruent trials (Gratton et al., 1992).

If cognitive control contributes to congruency effects in recognition, then a reasonable assumption is that recognition memory performance might improve selectively in conditions that are associated with up-regulated cognitive control in the study phase, as outlined above. For example, from a reactive control perspective (Braver, 2012), c-I trial transitions are associated with up-regulated cognitive control, as the system reacts to being ill-prepared for an incongruent item (Carter, Braver, Barch, Botvinick, Noll, & Cohen, 1998). If so, then recognition ought to be particularly good for incongruent items that were part of c-I trial transitions in the study phase. From a proactive control perspective (Braver, 2012), both i-C and i-I trial transitions are associated with up-regulated cognitive control, as up-regulated control for a preceding incongruent item ensures a heightened preparatory cognitive control state for any trial that follows an incongruent trial. If so, then recognition ought to be particularly good for congruent items that were part of i-C trial transitions, and for incongruent items that were part of i-I trial transitions.

Note that this proposed translation between congruency effects in on-line performance and congruency effects in recognition is not part of the conflict monitoring model itself. As such, it is important to state directly that the aim of our study is not to evaluate the conflict monitoring model. Rather, the conflict monitoring model provides, in our view, the most specific and clear predictions about the influence of list context on on-line congruency effects, which in turn makes it useful to describe how transient adaptations in cognitive control during a study phase might influence long-term memory performance in a following test phase. As such, the issue of primary interest to us here was whether list context during a study phase would influence recognition memory in a following test phase, with the conflict monitoring model used simply to point out the plausibility of such list context effects.

To address this issue, Experiment 1 examined whether the congruency effect in recognition reported by Rosner et al. (2015) is sensitive to the proportion of congruent items in the study phase. Experiments 2A and 2B addressed a related empirical issue, by comparing the congruency effect in recognition for mixed and blocked lists of congruent and incongruent items. Finally, in an analysis that combined data from the present study and those from two prior experiments in the study of Rosner, D'Angelo et al. (2015), we examined whether the congruency effect in recognition memory is sensitive to trial-to-trial sequences in the study phase. To foreshadow the results of these experiments and related analyses, the congruency effect in recognition proved to be a robust result, but one that was remarkably insensitive to list context. Experiments 3A and 3B then examined further the stimulus properties that give rise to particularly good recognition for incongruent items.

Experiment 1

The purpose of this experiment was to examine whether the congruency effect in recognition is sensitive to the proportion of congruent trials in the study phase. If cognitive control is up-regulated reactively on c-I trial transitions, and if this up-regulation in control strengthens memory encoding, then we might expect a larger congruency effect in recognition for the high proportion congruent condition (because c-I trials are common in this list context). Or alternatively, if cognitive control is up-regulated proactively on all trials that follow incongruent trials, then we might expect better recognition for the low proportion congruent condition than for the high proportion congruent condition (because i-I and i-C are common in this list context). Of course there may be other ways in which list context at study could influence recognition at test, so our aim was largely exploratory; would changes in proportion congruent list context at study affect recognition at test?

Method

Participants

Forty-eight participants from the McMaster University student pool provided informed consent and completed Experiment 1 in exchange for course credit. Participants (36 females) had a mean age of 19.0 years (SD = 4.4 years). All participants spoke English fluently and had normal or corrected-to-normal vision. The general protocol used in this and all subsequent experiments received approval from the McMaster Research Ethics Board.

Apparatus and stimuli

The stimuli were identical to those used in the study of Rosner, D'Angelo et al. (2015), and are depicted in Figure 1. Congruent and incongruent stimuli both consisted of two interleaved words presented in the middle of the screen against a black background. One of the two words was red and the other was green. Each word subtended 0.8º of visual angle vertically and 5.9º horizontally, and the two words together measured 1.0º vertically and 6.5º horizontally. The experiment used 360 five-letter words that were all high frequency nouns (Thorndike & Lorge, 1944).

The experimental program was run on a Dell computer using Psychopy® experimental software (Peirce, 2007, 2009). The stimuli were displayed on a 24-inch BENQ LED monitor, and responses were made using a microphone and keyboard. Participants sat approximately 50 cm from the monitor and were tested individually.

Figure 1. Congruent (left) and incongruent (right) items used by Rosner, D'Angelo et al. (2015) and in the present study. The locations of the words were counterbalanced such that the red target was in the top position for half of the stimuli, and in the bottom position for the other half of the stimuli.

Procedure

There were three phases in the experimental session. In the incidental study phase, a red word spatially interleaved with a green word appeared on every trial, and participants were asked to read the red word aloud as quickly and accurately as possible. Following the study phase there was a 10-minute distractor phase, in which participants completed math problems. The test phase then required participants to make old/new recognition memory decisions for items seen in the naming phase and for completely new items, as well as remember/know decisions for each item judged "old."

The study phase consisted of two blocks of 60 trials. One block contained a high proportion of congruent trials (.80 congruent) and the other contained a low proportion of congruent trials (.20 congruent), counterbalanced across participants. The two blocks were separated by a brief message on the screen indicating that participants were half-way through the naming task, but there was no overt warning that the proportion congruent changed across blocks. Each trial in the study phase began with a central fixation cross presented for 2000 ms, followed by a word pair presented for 1000 ms. RTs were recorded from the onset of the word pair to the onset of the vocal response, as detected by a microphone placed in front of the participant. Following offset of the word pair, a blank screen was presented until the experimenter coded the participants' response, after which the next trial began. Responses were coded as correct, incorrect, or a spoil, by pressing "1", "2", or "3", respectively, on the computer keyboard. Responses were coded as incorrect if a participant named aloud, in whole or in part, a word other than the target.

Responses were coded as a spoil if a spurious noise was suspected to have set off the microphone before a response was made (e.g., coughing or stuttering before responding).

Following the study phase, participants completed the math distractor phase, and then moved on to the surprise test phase. Detailed instructions for the test phase, including the distinction between "remembering" and "knowing" (Rajaram, 1993), were provided both orally and written on screen. Congruency (congruent/incongruent) was intermixed randomly across a single block of 240 test phase trials. Half of the test trials were old items previously seen in the study phase, and half were new items. Each trial began with a central fixation cross presented for 2000 ms. The fixation cross was followed by a test item and the words "OLD" and "NEW" on the bottom left and right of the screen, respectively. These stimuli remained on screen until participants responded by pressing the "A" key for old, or the "L" key for new. Participants were told to ignore the green distractor when making their old/new decision; the task was to make a recognition decision for the red target word. When an "old" response was made, the test item stayed on screen and the words "OLD" and "NEW" were replaced by "TYPE A" and "TYPE B", respectively. Participants were then required to make a remember/know judgment by pressing the "A" key if their old response was based on a Type A memory (a feeling of remembering) or the "L" key if their old response was based on a Type B memory (a feeling of knowing; see McCabe & Geraci, 2009).

Design

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

Whether the red target appeared on top of or below the green distractor was counterbalanced for study phase trials in each block and for new test phase trials, with half occurring above the distractor and half occurring below the distractor for each trial type. In the test phase, the old items were presented exactly as they appeared in the naming phase; that is, old items were the same two words presented in the same colours and in the same spatial positions during the study and test phases. In both blocks in the study phase, the congruent and incongruent items were randomly intermixed. In the test phase, the 120 old items were randomly intermixed with 60 congruent and 60 incongruent new items, for a total of 240 recognition test trials.

Two hundred and forty unique two-word items were used in the experiment; 120 items were used in both the study and test phases (labeled "old" items), and 120 items were foils presented only in the test phase (labeled "new" items). The 120 study phase items were divided into two sets of 60, one with .80 congruent items (high proportion congruent) and the other with .20 congruent items (low proportion congruent). Within the set of 240 test items, half of both the old and new items were congruent and half were incongruent. The 240 test items were constructed using a set of 360 five-letter high frequency words. The 360 words were randomly divided into six lists of 60 words (see Appendix A). Four of these lists were used to generate incongruent items (one list for targets and another for distractors, for each of the old and new items). The words that served as target and distractor for a particular item were selected randomly from the lists for each participant. The other two lists were used to generate old and new congruent items. The assignment of lists to the three possible roles for old items was counterbalanced across participants and the assignment of lists to the three possible roles for new items was randomized across participants.

Results

RTs for correct trials in the study phase were first submitted to the non-recursive with moving criterion outlier procedure of Van Selst and Jolicoeur (1994). This procedure eliminated 3.0 % of observations from further analyses. In addition, words that were named incorrectly in the naming phase were excluded from analysis of the recognition test phase, which eliminated a further 0.5 % of congruent trials and 5.1 % of incongruent trials from the recognition analyses. The remember/know data from the recognition phase were gathered only for exploratory purposes and are presented for the reader's benefit in Appendix B.[3]

Study Phase

Mean naming RTs and error rates were submitted to separate 2 x 2 repeated measure ANOVAs that treated proportion congruent (high/low) and trial type (congruent/incongruent) as within-subject factors. Mean RTs and error rates, collapsed across participants, are displayed in Table 1.

[3] Preliminary analyses for both the study and test phases first examined whether the counterbalancing variable of block order for proportion congruent (high/low) impacted performance. For the study phase, there were no significant effects involving the counterbalancing factor in the analysis of naming RTs, but one higher order interaction involving the counterbalancing factor in the analysis of errors. This interaction appeared to be driven by a small shift in the magnitude of the trial type x block effect for the two block orders, but generally error rates were low in all conditions and higher for incongruent than congruent trials in all conditions. For *d'* values in the test phase, there was one higher order interaction involving block order that appeared to be driven by a trend toward larger trial type effects in the second block of trials than in the first block of trials, a trend that we have seen in several other studies.

Table 1. Mean response times (ms) for the study phases of Experiments 1, 2A, and 2B (error rates in parentheses).

	Experiment 1		**Experiment 2A**		**Experiment 2B**	
	Proportion Congruent		**List Type**		**List Type**	
	High	**Low**	**Mixed**	**Blocked**	**Mixed**	**Blocked**
Incongruent	879 (.018)	846 (.034)	668 (.026)	671 (.022)	796 (.023)	768 (.019)
Congruent	711 (.003)	724 (.002)	547 (.003)	549 (.007)	653 (.006)	661 (.005)
Difference	168	122	121	122	143	107

In the analysis of naming RTs, there was a significant main effect of trial type, $F(1,46) = 226.760$, $p < .001$, $\eta_{p2} = .831$. Responses were faster for congruent trials (718 ms) than for incongruent trials (862 ms). There was also a significant proportion congruent by trial type interaction, $F(1,46) = 9.510$, $p = .003$, $\eta_{p2} = .171$. Responses were faster for congruent than for incongruent trials in both the high proportion congruent condition, $t(47) = 12.47$, $p < .001$, $d = 1.800$, and the low proportion congruent condition, $t(47) = 11.40$, $p < .001$, $d = 1.645$. The interaction therefore reflects the larger trial type effect in the high proportion congruent block (168 ms) than in the low proportion congruent block (122 ms).

In the analysis of error rates, there was a significant main effect of trial type, $F(1,47) = 54.96$, $p < .001$, $\eta_{p2} = .539$, as well as a significant main effect of proportion congruent, $F(1,47) = 5.97$, $p = .018$, $\eta_{p2} = .113$. The interaction between proportion congruent and trial type was also significant, $F(1,47) = 8.00$, $p = .007$, $\eta_{p2} = .146$.

Separate analyses for the two proportion congruent conditions revealed significant effects of trial type for both the low proportion congruent condition, $t(47) = 5.96$, $p < .001$, $d = 0.86$, and the high proportion congruent condition, $t(47) = 4.67$, $p < .001$, $d = .67$, with higher error rates for incongruent than congruent trials in both cases.

Recognition Test Phase

Mean proportion 'old' responses in the recognition test phase are presented in Table 2. As proportion 'old' was defined for old items but not for new items, we did not analyze these proportion 'old' data directly. Rather, proportion 'old' data for each condition and participant were used to compute signal detection measures of recognition sensitivity (*d'*) and bias (beta), which were then submitted to repeated measures ANOVAs that treated proportion congruent (high/low) and trial type (congruent/incongruent) as within-subject factors. Mean *d'* values, collapsed across participants, are presented in Table 3.

Table 2. Mean proportion "old" responses to old and new items as a function of trial type and proportion congruent in Experiment 1. The proportion congruent factor did not apply to new items.[4]

	Proportion Congruent		
	High	**Low**	**New**
Congruent	.624	.615	.226
Incongruent	.628	.647	.168

[4] The higher recognition sensitivity for incongruent than congruent trials here is most evident in the false alarm rates rather than the hit rates. This pattern of data recurs across experiments, and is addressed in detail at the end of Experiments 2A and 2B.

Table 3. Mean *d'* values from the recognition test phase for Experiments 1, 2A, and 2B.

	Experiment 1		Experiment 2A		Experiment 2B	
	Proportion Congruent		List Type		List Type	
	High	Low	Mixed	Blocked	Mixed	Blocked
Incongruent	1.43	1.47	1.41	1.37	1.75	1.52
Congruent	1.19	1.18	1.23	1.15	1.53	1.32
Difference	0.24	0.29	0.18	0.22	0.22	0.20

The analysis of *d'* revealed only a significant main effect of trial type, $F(1,47) = 20.57$, $p < .001$, $\eta_{p}^{2} = .304$. Recognition sensitivity was higher for incongruent trials (1.45) than congruent trials (1.18). Critically, the interaction between proportion congruent and trial type was not significant, $F(1,47) = 0.328$, $p = .569$. A Bayesian analysis focused on this interaction indicated positive support for the null hypothesis, $p(H_0|D) = .852$ (Masson, 2011).

The analysis of beta revealed a main effect of trial type, $F(1,47)= 4.648$, $p = .036$, $\eta_{p}^{2} = .090$. Responses to incongruent items (2.03) were associated with a more conservative criterion than responses to congruent items (1.60).

Discussion

Naming times in the study phase produced the standard effect of proportion congruent, with a larger congruency effect for the high proportion congruent condition. Although recognition sensitivity was higher for incongruent than congruent items, replicating our earlier finding (Rosner et al., 2015), this recognition sensitivity effect was no different for the high proportion congruent and low proportion congruent conditions. These results constitute a first piece of evidence that the encoding processes that underlie the congruency effect in recognition are not sensitive to list context.

Experiments 2A and 2B

In Experiments 2A and 2B, list context was manipulated by presenting congruent and incongruent trials mixed within the same list or blocked in separate lists. In a sense, this manipulation is similar to a proportion congruent manipulation; mixed lists included 50% congruent and 50% incongruent trials, and blocked lists included either 100% congruent or 100% incongruent trials. Again, if the congruency effect in recognition is sensitive to list context, then the magnitude of this effect may differ in the mixed and blocked conditions.

Method

Participants

Ninety-six participants from the McMaster University student pool provided informed consent and completed Experiment 2A or 2B in exchange for course credit or financial compensation at a rate of $12 per hour. The 48 participants (36 females) in Experiment 2A had a mean age of 18.7 years (*SD* = 1.9 years); the 48 participants (38 females) in Experiment 1B had a mean age of 19.8 years (*SD* = 2.4 years). In Experiment 2A, 24 participants were randomly assigned to each of the mixed and blocked list conditions. In Experiment 2B, the mixed and blocked conditions were run as two separate experiments (N = 24 each), but are combined here for ease of presentation. All participants spoke English fluently and had normal or corrected-to-normal vision. The general protocol used in these and all subsequent experiments received approval from the McMaster Research Ethics Board.

Apparatus and stimuli

The apparatus and stimuli were identical to those used in Experiment 1.

Procedure

Experiment 2A

The procedure included the same three phases as in Experiment 1. The study phase consisted of two blocks of 60 trials. In the blocked condition, congruent and incongruent items were presented in separate blocks, with block order counterbalanced across participants. In the mixed condition, congruent and incongruent items were intermixed randomly in both blocks. In both blocked and mixed conditions, a message on screen between the first and second blocks indicated to participants that they were half-way through the naming task.

Experiment 2B

The procedure was identical to Experiment 2A with the following exceptions. Congruency was blocked both at study and at test; that is, participants completed 60 study phase trials followed by 120 recognition test phase trials in each of two blocks. For the blocked condition, one congruency type (e.g., congruent items) was presented in the first block (study phase and test phase), and the other congruency type (e.g., incongruent items) was presented in the second block (study phase and test phase), with block order counterbalanced across participants. For the mixed condition, congruency was intermixed in both study-test blocks. The math distractor task was shortened to four minutes, and was administered after each of the two study phases and the first test phase. As there were two separate test phases in this experiment, the recognition test could not be a surprise for both test phases. As such, participants were given instructions for the recognition test before beginning the first study phase, and therefore encoding can be described as intentional in this experiment whereas it was incidental in Experiment 2A.

Design

The design was similar to Experiment 1 with the exception that list context was varied between-subjects by randomly intermixing or blocking congruent and incongruent trials, rather than within-subject by varying proportion congruent between study phase blocks. Other aspects of the design that differed for Experiments 2A and 2B are summarized below.

Experiment 2A

In the study phase, the 60 congruent and 60 incongruent items were intermixed in the mixed condition and presented in separate blocks in the blocked condition. In the test phase for both mixed and blocked conditions, 120 old items were randomly intermixed with 60 congruent and 60 incongruent new items, for a total of 240 recognition test trials.

Experiment 2B

In the mixed condition, 30 congruent and 30 incongruent items were intermixed in each of the two study phases. In each of the two test phases, 60 old items were randomly intermixed with 30 congruent and 30 incongruent new items, for a total of 120 recognition test trials. In the blocked condition, 60 items (all congruent or all incongruent) were presented in each of the two study phases. In each of the two test phases, the 60 old items were presented with 60 new items of the same trial type, for a total of 120 recognition test trials.

Results

RTs for correct trials in the study phase were submitted to the same outlier analysis as in Experiment 1 (Van Selst & Jolicoeur, 1994), which eliminated 2.6% and 3.3% of observations from further analyses in Experiments 2A and 2B, respectively. In addition, words that were named incorrectly in the study phase were excluded from analysis of the recognition test phase, which eliminated a further 0.5% of congruent trials and 2.4% of incongruent trials from the recognition analyses of Experiment 2A, and 0.6% of congruent trials and 2.1% of incongruent trials from the recognition analyses of Experiment 2B. The remember/know data from the recognition phase were gathered only for exploratory purposes and are presented for the reader's benefit in Appendix B.[5]

Study Phase

Mean RTs and error rates for each experiment were submitted to separate 2 x 2 mixed factor ANOVAs that treated list type (mixed/blocked) as a between-subjects factor and trial type (congruent/incongruent) as a within-subject factor. Mean RTs and error rates, collapsed across participants, are displayed in Table 1.

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[5] Preliminary analyses for both the study and test phases first examined whether the counterbalancing variable of block order influenced performance in the blocked condition. In Experiment 2A, no main effect of block order nor any interaction involving block order was significant in any of the analyses. In Experiment 2B, the only significant effect involving block order was a block order by trial type interaction in the analysis of *d'*, $F(1,22) = 5.291$, $p = .031$, $\eta_p^2 = .184$. This interaction appeared to be driven simply by better memory for the item type that was presented first, and was therefore treated as a spurious one for the present purposes. The data for all subsequent analyses for both Experiments 2A and 2B were collapsed across the block order factor.

Experiment 2A. In the analysis of naming times, there was a significant main effect of trial type, $F(1,46) = 158.84$, $p < .001$, $\eta_{p2} = .775$. Responses were faster for congruent trials (548 ms) than for incongruent trials (669 ms). In the analysis of error rates, there was also a significant main effect of trial type, $F(1,46) = 25.60$, $p < .001$, $\eta_{p2} = .357$, with higher error rates for incongruent trials (.024) than for congruent trials (.005). No other effects in either analysis were significant, all *p*'s > .10.

Experiment 2B. In the analysis of naming times, there was a significant main effect of trial type, $F(1,46) = 270.85$, $p < .001$, $\eta_{p2} = .855$. Responses were faster for congruent trials (657 ms) than for incongruent trials (782 ms). There was also a significant list type by trial type interaction, $F(1,46) = 5.490$, $p = .023$, $\eta_{p2} = .107$. Responses were faster for congruent than incongruent trials in both the mixed condition, $t(23) = 15.192$, $p < .001$, $d = 3.100$, and the blocked condition, $t(23) = 8.984$, $p < .001$, $d = 1.83$. The interaction therefore captures the larger magnitude of this effect in the mixed condition. In the analysis of error rates, there was a significant main effect of trial type, $F(1,46) = 12.715$, $p < .001$, $\eta_{p2} = .216$, with higher error rates for incongruent trials (.021) than for congruent trials (.006). No other effects were significant in either analysis, all *p*'s > .10.

Recognition Test Phase

Two analyses were conducted to evaluate performance in the test phase of each experiment. As in Experiment 1, the primary analysis focused on recognition sensitivity using signal detection measures. For this purpose, *d'* and beta were computed for each condition separately for each participant and submitted to mixed factor ANOVAs that treated list type (mixed/block) as a between-subjects factor and trial type (congruent/incongruent) as a within-subject factor. A secondary analysis was also conducted in which proportion "old" was submitted to a 2x2x2 mixed factor ANOVA that treated list type (mixed/block) as a between-subjects factor, and trial type (congruent/incongruent) and item type (old/new) as within-subject factors. This secondary analysis allowed us to look at hit and false alarm rates separately for patterns of interest. Mean *d'* values, collapsed across participants, are presented in Table 3. Mean proportion "old" responses, collapsed across participants, are displayed in Figure 2.

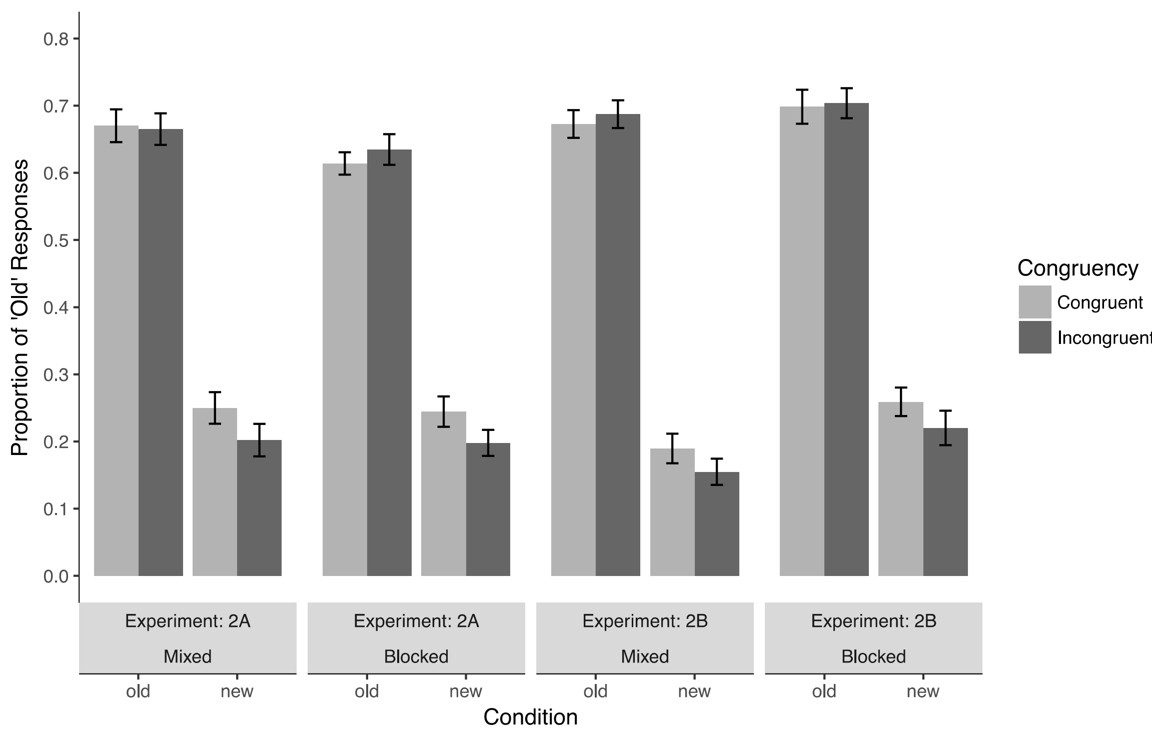

Figure 2. Mean proportion "old" responses to old and new items as a function of trial type and list type in Experiments 2A and 2B. Error bars in this and in all other figures reflect the standard error of the mean corrected to remove between-subject variability

(Morey, 2008).

Experiment 2A. The analysis of *d'* revealed only a significant main effect of trial type, $F(1,46) = 17.24$, $p < .001$, $\eta_{p2} = .273$. Recognition sensitivity was higher for incongruent (1.39) than congruent (1.19) trials. Critically, the interaction between list type and trial type was not significant, $F(1,46) = 0.122$, $p = .729$. A Bayesian analysis focused on this interaction indicated positive support for the null hypothesis, $p(H_0|D) = .874$ (Masson, 2011). Nonetheless, we had an a priori interest in evaluating the effect of trial type separately for the two list types. Separate analyses for the two list types revealed higher sensitivity for incongruent than congruent trials in both the mixed condition (1.41 vs. 1.23), $t(23) = 2.49$, $p = .020$, $d = 0.72$), and the blocked condition (1.37 vs. 1.15), $t(23) = 3.49$, $p = .002$, $d = 1.01$. The analysis of beta values revealed no significant effects, all *p*'s > .10.

The secondary analysis of proportion "old" responses revealed a significant main effect of item type, $F(1,46) = 376.74$, $p < .001$, $\eta_{p2} = .891$, a significant trial type by item type interaction, $F(1,46) = 11.896$, $p = .001$, $\eta_{p2} = .204$, and the three-way interaction between list type, trial type, and item type was not significant, $F(1,46) = 0.585$, $p = .480$. These results align with the primary analysis of sensitivity described above, indicating that participants could distinguish old from new items, that recognition sensitivity (hits – false alarms, in this case) was higher for incongruent than congruent trials, and that this effect did not differ for the mixed and blocked conditions (see Figure 2). Separate analyses of the hit and false alarm rates, collapsed across list type, revealed that hit rates were not significantly different for congruent and incongruent items, $t(47) = 0.489$, *p*

= .627, but that false alarm rates were significantly higher for congruent (.247) than incongruent (.200) items, $t(47) = 2.828$, $p = .007$, $d = 0.577$.

Experiment 2B. The analysis of *d'* revealed a significant main effect of trial type, $F(1,46) = 8.334$, $p = .006$, $\eta_{p}^{2} = .153$. Recognition sensitivity was higher for incongruent (1.64) than congruent (1.42) trials. Again, the interaction between list type and trial type was not significant, $F(1,46) = 0.002$, $p = 0.957$. A Bayesian analysis focused on this interaction again indicated positive support for the null hypothesis, $p(H_0|D) = .867$ (Masson, 2011). Separate analyses of the effect of trial type for the two list types revealed that sensitivity was higher for incongruent (1.75) than congruent (1.53) trials in the mixed condition, $t(23) = 2.899$, $p = .008$, $d = 0.592$. Although the trend was similar in the blocked condition, with higher sensitivity for incongruent (1.52) than congruent (1.32) trials, this effect did not reach significance, $t(23) = 1.644$, $p = .114$, $d = 0.335$. The analysis of beta values again revealed no significant effects, all *p*'s > .10.

The secondary analysis of proportion "old" responses revealed the same pattern as Experiment 2A. There was a significant main effect of item type, $F(1,46) = 460.55$, $p < .001$, $\eta_{p}^{2} = .909$, a significant trial type by item type interaction, $F(1,46) = 5.047$, $p = .030$, $\eta_{p}^{2} = .098$, and no significant three-way interaction between trial type, item type, and list type, $F(1,46) = 0.016$, $p = .899$. Participants successfully discriminated old from new items, they did so with higher sensitivity (hits – false alarms) for incongruent than congruent trials, and this effect did not differ for the mixed and blocked list types (see Figure 3). Separate analyses of the hit and false alarm rates, collapsed across list type, again revealed that hit rates did not differ for congruent and incongruent items, $t(47) =$

0.656, $p = .515$, but that false alarm rates were higher for congruent (.224) than incongruent (.188) items, $t(47) = 2.452$, $p = .018$, $d = 0.354$.

Discussion

The recognition results from Experiments 2A and 2B converge with those from Experiment 1. Recognition sensitivity was higher for incongruent than congruent items, and this effect did not differ for blocked and mixed list contexts. Moreover, across Experiments 1 and 2a, which had comparable 120 item study lists and a single recognition test, recognition performance for congruent and incongruent conditions was remarkably consistent across conditions with 20%, 50%, 80%, and 100% congruent or incongruent trials (see first four columns of Table 3). Together, the results of Experiments 1, 2A, and 2B suggest strongly that the recognition advantage for incongruent over congruent items is robust, and provide no evidence that this effect is sensitive to list context.

One result that was not anticipated concerns the naming times in Experiment 2A. In particular, although the congruency effect in naming times was larger for high proportion congruent than low proportion congruent items in Experiment 1, and larger for mixed than blocked lists in Experiment 2B, there was no difference in congruency effects for mixed and blocked lists in Experiment 2A. It is unclear to us at this point why uncertainty about trial type in mixed lists failed to result in larger congruency effects than for blocked lists in Experiment 2A, when corresponding effects appear to have been observed in two other experiments.

Sequential (trial-to-trial) Congruency Effects

As a follow-up to Experiments 1, 2A, and 2B, we conducted a direct test of the dependence of the congruency effect on list context at the trial-to-trial level. To conduct a sensitive analysis of this issue, substantial data from experiments with randomly intermixed study phase trials were required. Our analysis included data from Experiments 1 (24 participants) and 2 (48 participants) from the Rosner, D'Angelo at al. (2015) study and the mixed condition of Experiment 2A of the present study (24 participants), for a total of 96 participants. In all of these experiments, participants named targets for 60 congruent and 60 incongruent items randomly intermixed at study, and made recognition decisions for 120 congruent (60 old/60 new) and 120 incongruent (60 old/60 new) randomly intermixed items at test. Two analyses were conducted, one for RTs in the study phase and another for recognition sensitivity (*d'*) in the test phase. The two within-subject factors in both analyses were current trial type (congruent/incongruent) and previous trial type (congruent/incongruent). Mean RT and recognition sensitivity (*d'*) are presented in Figure 3.

In the RT analysis, there was a significant interaction between current trial type and previous trial type, $F(1,95) = 3.98$, $p = .049$, $\eta_{p2} = .040$ (see Figure 3 left panel). The congruency effect was larger following congruent trials than following incongruent trials, in line with many previous studies of sequential congruency effects (Gratton et al., 1992). Subsequent analyses revealed that responses were faster for congruent trials that followed congruent trials than for congruent trials that followed incongruent trials, $t(95) = 3.71$, $p < .001$, $d = 0.379$, whereas the corresponding effect was not significant for incongruent trials, $t(95) = 0.012$, $p = .99$.

In the analysis of recognition sensitivity (d'), the interaction between current trial type and previous trial type was also significant, $F(1,95) = 8.75$, $p = .004$, $\eta_{p2} = .084$, although in this case the congruency effect was larger for previous incongruent than previous congruent trials. Subsequent analyses revealed that sensitivity was higher for congruent trials that followed congruent trials than for congruent trials that followed incongruent trials, $t(95) = 2.31$, $p = .023$, $d = 0.236$, whereas the corresponding effect for incongruent trials did not reach significance, $t(95) = 1.63$, $p = .107$.

Generally speaking, both of the sequence analyses revealed significant trial-to-trial effects. Interestingly, these effects were limited to performance for current congruent trials, a result that is in accord with a recent proposal by Schlaghecken and Martini (2012). These researchers noted that trial-to-trial adaptations in control are often more robust for current congruent than current incongruent trials. More important, the results of the recognition sequence analysis do not follow in any obvious way from predictions outlined earlier about how cognitive control adaptations in the study phase might influence recognition performance in the test phase. Whereas we conjectured that recognition for c-I trial transitions might benefit from a reactive adjustment in cognitive control, the results in Figure 3 (right panel) offer no support for this prediction. We also conjectured that any trials following an incongruent trial might benefit from a proactive adjustment in cognitive control, but again the results in Figure 3 (right panel) offer no support for this prediction; overall performance for trials following congruent trials is near equivalent to that for trials following incongruent trials. Neither does it appear that a combination of reactive and proactive control adjustments as outlined above would produce the results we observed.

In summary, the sequential congruency analysis did reveal evidence of a modest list context effect on recognition. However, this trial-to-trial list context effect did not align in any obvious way with how adjustments in either reactive or proactive cognitive control might influence recognition.

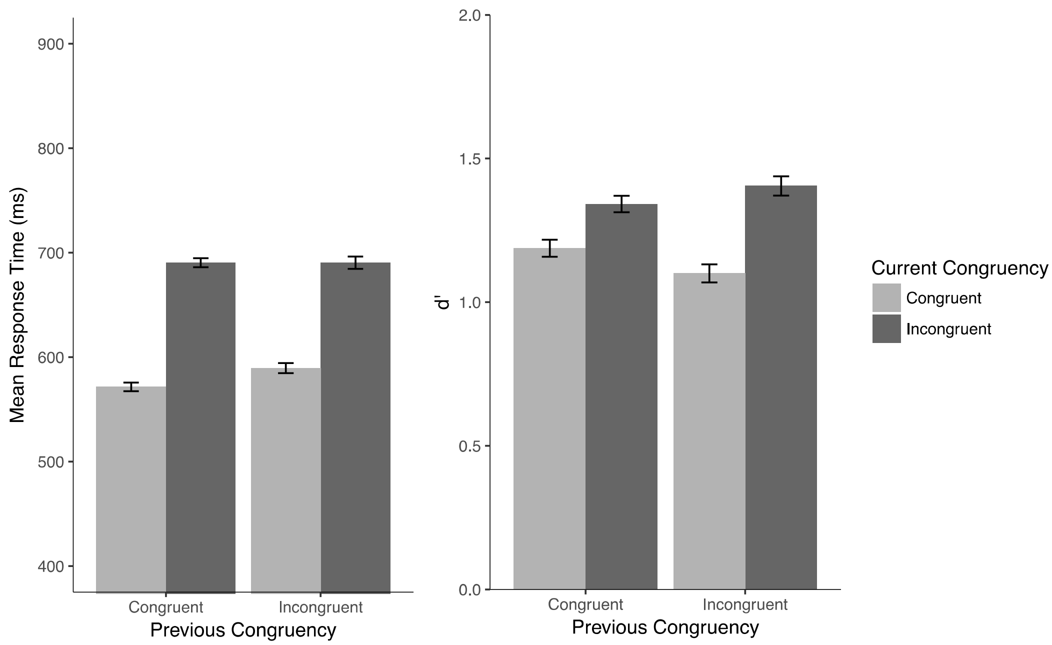

Figure 3. Mean response time (left panel) and *d'* (right panel) as a function of previous and current trial congruency, in a combined re-analysis of Experiments 1 and 2 from Rosner, D'Angelo et al. (2015) and Experiment 2A from the present study.

Perceptual Fluency Effects at Test

A noteworthy finding in Experiments 2A and 2B (see also Experiment 1) was that false alarm rates were lower for incongruent than congruent trials, whereas hit rates did not differ for the two trial types. Lower false alarm rates for incongruent than congruent items were also reported by Rosner, D'Angelo et al. (2015). Although this pattern of results might appear to imply that congruency influences performance only for the 'new' items in the recognition test, this interpretation leaves one without an explanation for the sensitivity effects observed reliably in our *d'* measure. To explain this pattern of results, we propose a two-process account as follows: (1) processing fluency differences for congruent and incongruent items at the time of test influence recognition judgments similarly for both old and new items (Jacoby & Dallas, 1981); and (2) encoding strength differences for congruent and incongruent items during the study phase influence recognition performance in a way that counters the influence of perceptual fluency on hit rates at the time of test. This two-process interpretation of hit rates is depicted in Figure 4. Processing fluency at test is proposed to push both hit and false alarm rates higher for congruent than incongruent items. This effect occurs because fluency associated with seeing the same word twice on congruent test trials is attributed to that item having been seen during the study phase (Jacoby & Whitehouse, 1989). In contrast, incongruency during the study phase up-regulates encoding, and drives hit rates higher for incongruent than congruent items. Together, these two processes push hit rates in opposite directions. Consequently, a null effect in hit rates (together with higher false alarms for congruent than incongruent trials) implies that the influence of congruency at the time of study is offset by an equal and opposite effect of perceptual fluency at test (see also Joordens & Hockley, 2000). Of course, the influence of congruency at study on subsequent recognition is captured by the *d'* analysis, which consistently revealed higher sensitivity for incongruent items.

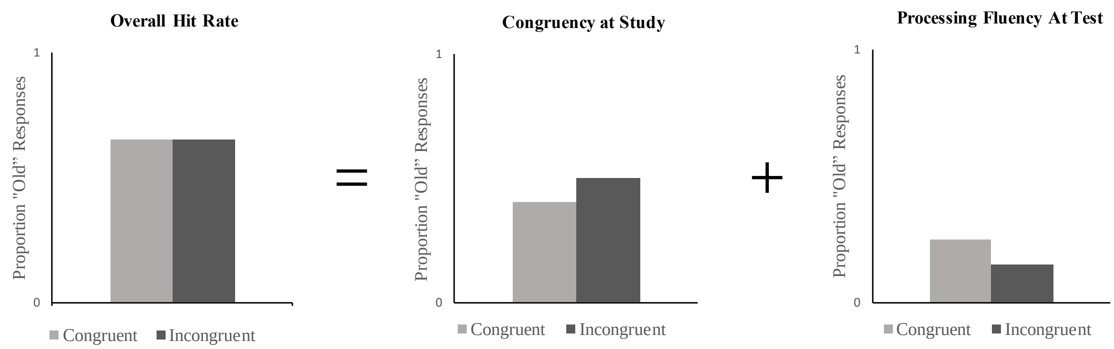

Figure 4. A schematic of the two-process account of equivalent hit rates for congruent and incongruent items observed in Experiments 2A and 2B.

Experiments 3A and 3B

The results of Experiments 1, 2A, and 2B support the proposal that the congruency effect in recognition is related primarily to item processing differences between congruent and incongruent items, rather than to the context in which those items are processed. Here, we turn our attention to the particular properties of item processing that drive this effect by contrasting performance with a single word baseline condition. If higher recognition sensitivity for incongruent than congruent items is caused by response conflict on incongruent trials, then recognition sensitivity ought to be higher for incongruent items than for single word items, but not higher for congruent items than for single word items (neither congruent items nor single word items should trigger response conflict). In contrast, if higher recognition sensitivity for incongruent than congruent items is caused by the distinct perceptual processing demands associated with incongruent items, then recognition sensitivity may be higher for congruent items than for single word items. This prediction stems from the idea that both interleaved item types in our study (incongruent and congruent items) may be more difficult to process perceptually than single word items. That is, incongruent items may be the most difficult to process, followed by congruent items, and then single word items.

To address this issue, we conducted two additional experiments that compared incongruent and congruent items separately to a single word baseline. In Experiment 3A, we contrasted recognition performance for incongruent items (as in Experiments 2A and 2B) and single word items (i.e., target words presented alone without a distractor). In Experiment 3B, we contrasted recognition performance for congruent items (as in Experiments 2A and 2B) and single word items.

Method

Participants

Ninety-six participants from the McMaster University student pool completed Experiments 3A and 3B in exchange for course credit or financial compensation at a rate of $12 per hour. The 48 participants (32 females) in Experiment 3A had a mean age of 18.8 years (SD = 2.7 years); the 48 participants (43 females) in Experiment 3B had a mean age of 18.7 years (SD = 1.6 years). All participants spoke English fluently and had normal or corrected-to-normal vision.

Apparatus and Stimuli

The apparatus and stimuli were identical to Experiment 2A with the following exceptions. In Experiment 3A, the two trial types were incongruent and single word items. In Experiment 3B, the two trial types were congruent and single word items. Single word trials in both Experiments 3A and 3B were created by presenting the previously green distractor words for items from Experiment 2A in the same color as the black background of the computer display.[6]

Procedure and Design

The procedure and design for both Experiments 3A and 3B were identical to the mixed condition in Experiment 2A with two exceptions. Instead of two distinct blocks of 60 trials each in the study phase, participants completed a single block of 120 trials. In Experiment 3A, incongruent and single word trials were randomly intermixed at both study and test. In Experiment 3B, congruent and single word trials were randomly intermixed at both study and test.

Results

Study Phase

The outlier analysis of correct RTs (Van Selst & Jolicoeur, 1994) eliminated 2.5% and 2.8% of observations from Experiments 3A and 3B, respectively. In addition, words that were named incorrectly in the study phase were excluded from analysis of the recognition test phase, which eliminated a further 1.0% of single word trials and 2.9% of

[6] In addition, in Experiment 2A the stimuli were presented on a 20-inch HP LCD monitor rather than a 24-inch BENQ LED monitor.

incongruent trials from the recognition analyses of Experiment 3A, and 0.5% of single word trials and 0.5% of congruent trials from the recognition analyses of Experiment 3B. Mean RTs and error rates for each experiment were submitted to two-tailed paired sample *t* tests that compared single word and incongruent trials in Experiment 3A, and single word and congruent trials in Experiment 3B. Mean RTs and error rates, collapsed across participants, are displayed in Table 4.

Table 4. Mean response times (ms) for the study phase (error rates in parentheses) of Experiments 3A and 3B.

	Experiment 3A		**Experiment 3B**
Incongruent	755 (.029)	**Congruent**	631 (.005)
Single	566 (.010)	**Single**	590 (.005)
Difference	189	**Difference**	41

Experiment 3A. In the analysis of RTs, responses were faster for single word trials (566 ms) than for incongruent trials (755 ms), $t(47) = 19.452$, $p < .001$, $d = 2.81$. In the analysis of error rates, participants made more errors on incongruent trials (.029) than on single word trials (.010), $t(47) = 4.737$, $p < .001$, $d = 0.684$.

Experiment 3B. In the analysis of RTs, responses were faster for single word trials (590 ms) than for congruent trials (631 ms), $t(47) = 6.585$, $p < .001$, $d = 0.950$. Error rates were low, and did not differ across the two trial types, $p > .10$.

Recognition Test Phase

In the primary analyses, *d’* and beta values were submitted to two-tailed paired sample *t* tests that compared single word and incongruent trials in Experiment 3A, and single word and congruent trials in Experiment 3B. Mean *d'* values, collapsed across participants, are presented in Table 5. In the secondary analyses, proportions "old" for each condition were submitted to repeated measures ANOVAs that treated trial type (single word/incongruent in Experiment 3A, single word/congruent in Experiment 3B) and item status (old/new) as within-subject factors. Mean proportions "old," collapsed across participants, are presented in Figure 5. The remember/know data from the recognition phase are presented in Appendix B.

Table 5. Mean *d'* values from the recognition test phase of Experiments 3A and 3B.

	Experiment 3A		**Experiment 3B**
Incongruent	1.47	**Congruent**	1.28
Single	1.16	**Single**	1.18
Difference	0.31	**Difference**	0.10

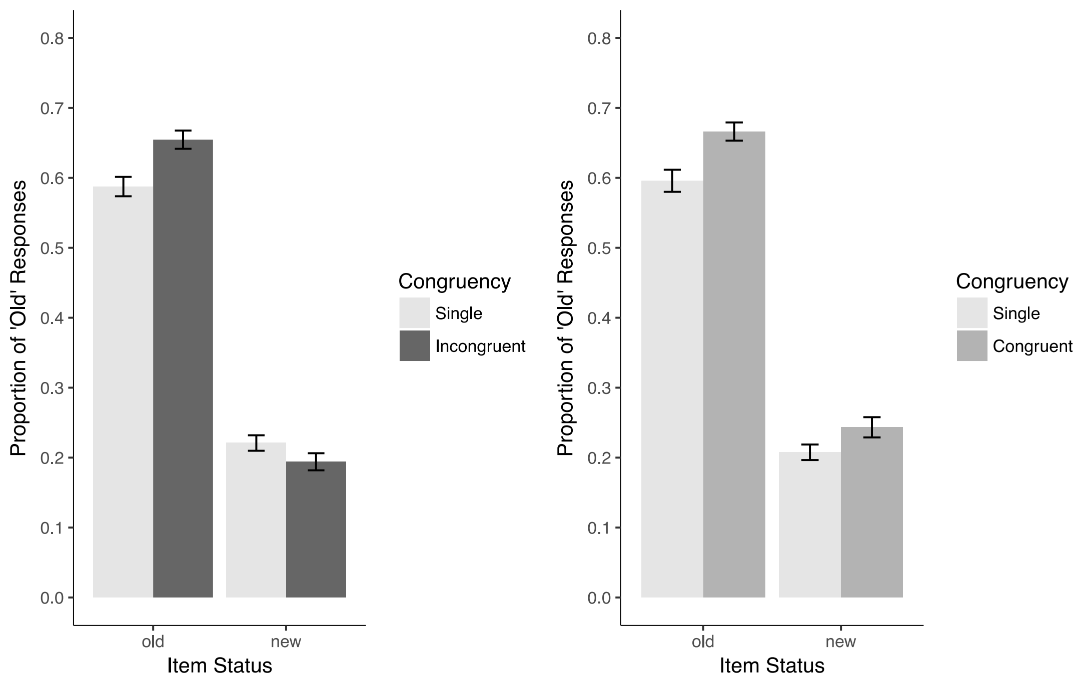

Figure 5. Mean proportion "old" responses for Experiments 3A (left panel) and 3B (right panel).

Experiment 3A. The analysis of *d'* revealed higher recognition sensitivity for incongruent trials (1.47) than for single word trials (1.16), $t(47) = 3.814$, $p < .001$, $d = 0.551$. A corresponding analysis of beta revealed no significant difference between trial types, $t(47) = 0.715$, $p = .478$.

The secondary analysis of proportion "old" responses revealed a significant main effect of item status, $F(1,47) = 778.260$, $p < .001$, $\eta_{p2} = .943$, as well as a significant interaction between trial type and item status, $F(47) = 20.618$, $p < .001$, $\eta_{p2} = .306$. Participants successfully discriminated old from new items, and they did so with higher sensitivity (hits – false alarms) for incongruent than for single word trials (Figure 5 left panel). Separate analyses of the hit and false alarm rates revealed higher hit rates for incongruent (.654) than for single word items (.588), $t(47) = 3.733$, $p < .001$, $d = 0.539$, and higher false alarm rates for single word (.221) than for incongruent (.194) trials, although the false alarm difference only approached significance, $t(47) = 1.926$, $p = .060$, $d = 0.278$.

Experiment 3B. The analysis of *d'* revealed significantly higher recognition sensitivity for congruent trials (1.28) than for single word trials (1.18), $t(47) = 2.495$, $p = .016$, $d = .360$. A corresponding analysis of beta revealed no significant difference between trial types, $t(47) = 0.593$, $p = .556$.

The secondary analysis of proportion "old" responses revealed significant main effects of item status, $F(1, 47) = 457.343$, $p < .001$, $\eta_{p2} = .907$, and trial type, $F(1, 47) = 18.494$, $p < .001$, $\eta_{p2} = .282$, as well as a significant interaction between item status and trial type, $F(1,47) = 5.674$, $p = .021$, $\eta_{p2} = .106$. Participants were able to discriminate old from new items, they made more "old" responses to congruent (.455) than to single word items (.402), and recognition sensitivity (hits – false alarms) was higher for congruent than for single word items (Figure 5 right panel). Separate analyses of the hit and false alarm rates revealed that these rates were both higher for congruent than for single word trials, $t(47) = 4.275$, $p < .001$, $d = 0.617$, and $t(47) = 3.035$, $p = .004$, $d = 0.438$, respectively.

Combined analysis of Experiments 3A and 3B. In a final analysis, *d'* values were submitted to a 2x2 mixed factor ANOVA that treated trial type (single word/interleaved) as a within-subject factor and experiment (3A/3B) as a between-subjects factor. There was a significant main effect of trial type, with higher sensitivity for interleaved words (1.38) than for single words (1.17), $F(1,94) = 20.566$, $p < .002$, $\eta_{p}2 = 0.180$. There was also a significant interaction between experiment and trial type, $F(1,94) = 4.992$, $p = .028$, $\eta_{p}2 = 0.05$, which was driven by a larger sensitivity difference in Experiment 3A (single word versus incongruent) than in Experiment 3B (single word versus congruent).

Discussion

Recognition sensitivity was higher for incongruent than for single word items in Experiment 3A, and higher for congruent than for single word items in Experiment 3B. Moreover, the effect in Experiment 3A was larger than the effect in Experiment 3B. The entirety of this pattern of results cannot be explained by response conflict, as neither congruent items nor single word items should elicit response conflict. Instead, the results are more consistent with either of the two following accounts.

According to the perceptual processing difficulty account, the three item types in these experiments vary along a continuum of processing difficulty, with single word items being easiest to process and incongruent items being most difficult to process. If perceptual processing difficulty triggers an up-regulation of item encoding, then recognition ought to be best for incongruent items, and worst for single word items, which is the pattern we observed. Alternatively, both response conflict and perceptual processing difficulty may contribute to the effects observed here. By this hybrid account, the difference between congruent and single word items observed in Experiment 3B may be related to perceptual processing difficulty, whereas the larger difference between incongruent and single word items observed in Experiment 3A may be related to both perceptual processing difficulty and response conflict.

At this point, there is little to choose between these two accounts other than the relative parsimony of the perceptual processing difficulty account, and so additional research will be needed on this issue. Nonetheless, the results of the present experiment do show clearly that response conflict is not the only factor responsible for elevated recognition sensitivity for incongruent items relative to a single word baseline.

General Discussion

Two recent studies reported a relation between selective attention demands at study and recognition performance at test (Krebs et al., 2013; Rosner, D’Angelo et al., 2015). Both studies reported higher recognition sensitivity for items with high selective attention demands (incongruent trials) than for items with low selective attention demands (congruent trials). The present study examined whether this effect is sensitive to list context of items during the study phase, and whether response conflict on its own or in combination with perceptual processing difficulty contributes to the high recognition sensitivity of incongruent items.

In Experiment 1, list context during the study phase was manipulated by varying proportion congruent, and in Experiments 2A and 2B, list context during the study phase was manipulated by randomly intermixing or blocking congruent and incongruent items. In all three experiments, recognition sensitivity was higher for incongruent than for congruent items, and this effect did not vary as a function of list context. An analysis of sequential congruency effects did reveal a small list context effect: Congruent trials that followed congruent trials were recognized with higher sensitivity than congruent trials that followed incongruent trials. However, this effect is not easily explained by any known principle of list context effects on performance in on-line selective attention tasks. Taken together, we conclude that the congruency effect in recognition is a robust effect that is largely insensitive to list context.

In Experiments 3A and 3B, we contrasted recognition performance for incongruent and congruent items with a single word baseline condition. Recognition sensitivity was higher for incongruent items than for single word items in Experiment 3A, and also higher for congruent items than for single word items in Experiment 3B. However, the effect in Experiment 3A was larger in magnitude than that in Experiment 3B. Together, these results suggest that perceptual processing difficulty plays an important role, perhaps together with response conflict, in increasing recognition sensitivity for incongruent items relative to congruent and single word items.

Attention Adaptation to Perceptual Processing Difficulty

The results from the present study suggest that recognition performance varies as a function of processing demands of study phase items, and that this effect is largely insensitive to the context in which those items are experienced. Thus, transient shifts of attention in response to perceptual processing difficulty—perhaps in addition to response conflict—appears to strengthen the encoding of incongruent items as they are processed. Below we highlight a number of other findings from the memory literature that point to a connection between perceptual processing difficulty and strength of item encoding.

Words presented briefly and pattern masked during a study phase are remembered better than those left unmasked at study (Nairne, 1988). This "perceptual interference effect" (Hirshman & Mulligan, 1991; Hirshman, Trembath & Mulligan, 1994; Mulligan, 1996, 1999) has been attributed to an up-regulation of higher-order non-visual processing (e.g., phonology, semantics) in response to difficult-to-process masked words, which results in better memory than their unmasked counterparts. Mulligan and colleagues posit that this compensatory processing adaptation is dependent on the processing demands of the item itself more so than the context in which the item occurs, a finding that fits with the insensitivity of congruency effects to list context reported here.

Other studies have shown that words with degraded features are better remembered than words presented intact (Besken & Mulligan, 2014; Diemand-Yauman, Oppenheimer, & Vaughn, 2011; Rosner, Davis & Milliken, 2015; but see Yue, Castel & Bjork, 2013). For example, Rosner, Davis et al. (2015) reported better recognition of words presented at study in a blurry font than in a clear font, both when these two trial types were intermixed and when they were blocked in separate lists. Besken and Mulligan (2014) reported a similar finding when auditorily presented words were degraded at study with inter-spliced silences. Interestingly, such effects are often not in line with judgments of learning (JOLs) on the likelihood that study items will be remembered on a subsequent memory test, as higher JOLs are often observed for easier-to-process trial types (Besken & Mulligan, 2013; 2014). A possibly related effect was reported recently by Rosner, Lopez-Benitez, D'Angelo, Thomson, and Milliken (2018). In the study phase of the Rosner et al. study, target words were preceded immediately by an identical word (repeated items) or a different word (non-repeated items), and of course naming times were faster for repeated than non-repeated items. However, recognition in a subsequent test phase was superior for non-repeated than for repeated items. Again, this result illustrates that processing difficulty (or disfluency) can enhance memory encoding.

A recent study also examined processing difficulty and conflict effects on memory performance using a change detection paradigm (Ortiz-Tudela, Milliken, Botta, LaPointe, & Lupiàñez, 2017). Target objects in the change detection study phase were semantically congruent (cow in a prairie) or incongruent (cow on a street) with the natural scene contexts in which they were embedded. An interesting property of change detection performance is that it is typically better for semantically incongruent than for semantically congruent targets (Hollingworth & Henderson, 2000; LaPointe, Lupianez & Milliken, 2013; see also Loftus & Mackworth, 1978). Recognition performance in a following test phase was better for the harder to detect congruent targets from the earlier change detection study phase, a result that favours the view that processing difficulty can enhance memory encoding.

Time-on-Task

We have proposed that processing difficulty leads to an attention adaptation that enhances memory encoding. However, it is worth considering whether an extended period of time dedicated to task completion, without any attention adaptation, is sufficient to enhance memory encoding. Although this time on task account—essentially a "total time" account (see Cooper & Pantle, 1967)—might seem preferable on grounds on parsimony, it has a number of shortcomings.

First, both Krebs et al. (2013) and Rosner, D’Angelo et al. (2015) conducted additional analyses to rule out a time on task account of congruency effects on recognition. For example, Rosner, D’Angelo et al. noted that naming times in the study phase were not related to whether an item was later remembered or forgotten. They also compared recognition sensitivity for the fastest named half of the incongruent study items and the slowest named half of the congruent study items, and found higher sensitivity for the incongruent items despite overall faster naming responses for these items. These results imply that time on task (i.e., naming time) on its own does not account for the higher recognition sensitivity for incongruent items.

Second, Rosner, Davis et al. (2015) reported that a low level of perceptual blur that significantly lengthens naming times in a study phase does not enhance recognition memory in a following recognition test phase (see also Yue et al., 2013). In contrast, a higher level of perceptual blur does both slow naming times at study and enhance recognition memory at test. These results suggest that perceptual degradation affects naming times in the study phase in a continuous manner, but that perceptual degradation at study must surpass some threshold to induce processing that enhances memory encoding. In a follow-up study of this same phenomenon, we observed greater pupil dilation to the high level of blur relative to clear items, but not to the low level of blur relative to the clear items (Davis, Hashemi, Milliken, & Bennett, 2018). Together, these results strongly suggest that a processing adaptation to perceptual degradation, rather than a passive increase in time on task, enhances memory encoding and subsequent recognition performance.

Third, a time on task account that is not further specified makes a blanket prediction that memory performance should be better under any conditions in which the time spent on an encoding task is high rather than low. Clearly, this is not the case (Craik & Tulving, 1975; for an overview, see Craik, 2002). Two recent studies that focus specifically on the relation between attention and memory encoding make this point clearly. Richter and Yeung (2012) examined the influence of task switching on memory performance. They demonstrated that memory for relevant information on trial *n* was worse following a task switch than following a task repetition from trial *n*-1, despite task switches being the more difficult trial type. Ortiz-Tudela, Milliken, Jiménez, and Lupiàñez (2018) examined the influence of spatial cueing on recognition performance. Across seven spatial cueing experiments, response times during an incidental study phase were faster for words presented in validly cued locations than for words presented in invalidly cued locations, and yet in none of these experiments was subsequent recognition sensitivity superior for invalid than valid trials. This null result in recognition suggests that an expectation mismatch, or prediction error, that increases time on task is not sufficient to enhance recognition sensitivity. Clearly, what is needed is further research to pin down more precisely the processing adaptations to encoding difficulties that do enhance memory encoding.

Congruency Influences at Study and Test

An interesting property of the recognition results reported here is that congruency appears to influence both memory encoding during the study phase, and inferences about prior experience in the recognition test phase. We proposed a two-process account to explain this property of the data (see Figure 5): (1) memory encoding is up-regulated for incongruent relative to congruent items during the study phase, and this memory encoding effect is captured by the consistently higher recognition sensitivity for incongruent than congruent items (Experiments 1, 2A, 2B; see also Rosner, D'Angelo et al., 2015); and (2) processing fluency is higher for congruent than incongruent items (both old and new) during the recognition test phase, and this processing fluency due to the perceptual characteristics of the test items is misattributed to prior experience (Jacoby & Whitehouse, 1989). Because both of these processes can be expected to contribute to hit rates, and because they push hit rates in opposite directions, we often observed no hit rate difference for congruent and incongruent items (Experiments 1, 2A, 2B). In other words, up-regulated memory encoding for incongruent items pushed hit rates higher for incongruent relative to congruent items, while higher processing fluency for congruent items pushed hit rates higher for congruent relative to incongruent items.

Converging evidence for this two-process account was observed in Experiment 2 of the earlier Rosner, D'Angelo et al. (2015) study. In this experiment, congruency was manipulated at study but not at test, which would eliminate the putative processing fluency effect described above. In the absence of the processing fluency effect, the only putative process remaining is the up-regulated encoding for incongruent relative to congruent trials. In line with this proposal, hit rates were significantly higher for incongruent than congruent items. An interesting focus for additional research is whether these two influences are in some way related. Might processing disfluency serve as a cue for up-regulated memory encoding?

Beyond Recognition

To date, congruency effects on memory performance have been studied exclusively with recognition tasks (Krebs et al., 2013; Rosner, D'Angelo et al., 2015). To our knowledge, no study has examined whether a similar effect would occur in other types of memory tasks. This issue is an important one, as it may help to specify the nature of the memory representations that are enhanced by processing difficulty. For example, it would be useful to know whether superior memory for incongruent items would be observed in a free recall task, as free recall and recognition are widely assumed to involve different processes. Whereas recognition depends primarily on retrieval of item-specific information, free recall depends on retrieval of both item-specific and relational information (Hunt & Einstein, 1981; Kintsch, 1970; McDaniel & Bugg, 2008; Tversky, 1973). Moreover, it has been argued that difficult-to-process or unusual stimuli favour the encoding of item-specific information (Mulligan, 1999; McDaniel & Bugg, 2008). By this view, processing difficulty effects on memory performance ought to be most robust in recognition tasks. Indeed, a family of effects—including the perceptual interference effect discussed earlier—reviewed by McDaniel and Bugg (2008) have precisely this property; they are more robust in recognition than free recall.

Given this body of work, it seems possible that the perceptual difficulty of incongruent relative to congruent items promotes the encoding of item-specific information over relational information. This benefit for item encoding is then reflected in superior recognition, precisely because recognition memory tasks depend on the retrieval of item-specific information. Clearly, it will be important to examine whether the memory benefit for incongruent trials can be observed in free recall and other memory tasks.

Conclusion

The results of the present study demonstrate that the recognition benefit for incongruent relative to congruent selective attention trials is robust to manipulations of list context, unlike effects of on-line performance discussed in the cognitive control literature. Instead, we propose that this effect is one of a broader class of effects in which perceptual encoding difficulty leads to attention adaptations that benefit recognition. Importantly, these attention adaptations depend on the processing demands of the item itself rather than the context in which the item is presented. The precise processes that underlie attention adaptations that respond to perceptual encoding difficulty certainly merit further study.

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Appendix A: Word lists used in Experiments 1 and 2

(Experiment 3 used a different set of six lists comprised of the same words)

Word List 1: ADULT, BLIND, BRIDE, BROOK, CABLE, CATCH, CHAIR, CHARM, CLEAN, CLIMB, COAST, CURVE, DAILY, DRIVE, DROVE, FANCY, FLASH, GLARE, GLOVE, GROUP, GUARD, GUIDE, IDEAL, JEWEL, JUICE, MAJOR, MONEY, MONTH, NOVEL, OLIVE, PILOT, PITCH, PURSE, RIVAL, SAUCE, SHEER, SHOCK, SHORT, SIGHT, SOLID, SPRAY, STAMP, START, STEEP, STERN, STORY, STRIP, SWIFT, TABLE, THROW, TITLE, TOTAL, TOWER, TRADE, TRUTH, UNCLE, WATCH, WATER, WHEEL, WORST

Word List 2: AGENT, ANGLE, BASIS, BIRTH, BREAD, BREAK, BRICK, CABIN, CHILL, CHOKE, CIGAR, CLASS, CLERK, COUNT, CRASH, CREEK, EMPTY, EVENT, EXTRA, FLOOR, FRONT, FROWN, GLASS, GLEAM, KNOCK, LIGHT, MAGIC, MATCH, MOTOR, MOVIE, NOBLE, OFFER, PARTY, PEACH, PHONE, PIANO, PROOF, PUPIL, RADIO, RANCH, SCORE, SHAPE, SHIRT, SLIDE, SLOPE, SMART, SPEED, STAKE, STATE, STRAW, SWEAR, TODAY, TOUGH, TRACE, TRAIN, UPPER, VALUE, VOICE, WORLD, WOUND

Word List 3: ANKLE, ASIDE, BATHE, BENCH, BLANK, BRAND, CANDY, CHAIN, CHASE, CHEER, CHEST, CHIEF, CLAIM, CLOUD, CRAWL, DELAY, DREAM, FAINT, FEVER, FLAME, GUESS, HEART, HONEY, HORSE, INNER, ISSUE, LAUGH, LEAST, LIMIT, LUNCH, MIGHT, MOUTH, MUSIC, NERVE, NURSE, OCEAN, ONION, OWNER, PAINT, PLANE, PLANK, POUND, PRESS, PRIZE, RANGE, ROUND, SCALE, SHAME, SLEEP, SPOON, STOOP, STUDY, STUFF, TASTE, TENSE, TOAST, TREAT, TRICK, TWIST, YIELD

Word List 4: BLAZE, BLOCK, BLOOM, BRAIN, BRUSH, BUNCH, CHEEK, CHILD, CLIFF, COURT, CROWN, CRUMB, DRAIN, DRESS, EARTH, ELBOW, FLOUR, GLORY, GRASS, HURRY, JELLY, JUDGE, LINEN, ORDER, OTHER, PAUSE, PENNY, PLANT, PORCH, PRIDE, PRINT, QUOTE, REBEL, RIGHT, ROUGH, SCENE, SERVE, SHAKE, SHARE, SHARP, SHEET, SHELL, SKIRT, SPELL, SPOIL, SPOKE, STAGE, STALK, STEEL, STICK, STOLE, STONE, SUGAR, TEETH, TIMER, TRACK, TRAIL, TRUNK, WAGON, WHILE

Word List 5: ACTOR, BOAST, CLOCK, CORAL, COVER, CRACK, CROSS, DEPTH, DOUBT, ELECT, FENCE, FLOAT, FLUSH, FRAME, FRUIT, GRADE, GRAIN, GRASP, GRIEF, GUEST, KNIFE, LEMON, LEVEL, MIDST, NOISE, OPERA, ORGAN, PASTE, PEARL, PIECE, POINT, PRICE, QUICK, QUIET, REACH, RIVER, ROUTE, SALAD, SATIN, SCARE, SCENT, SHIFT, SHINE, SHORE, SLICE, SMALL, SMELL, SPACE, SPLIT, STAND, STEAL, STILL, STOCK, STORE, SWEET, SWING, THING, TROOP, TRUCK, WHIRL

Word List 6: ALARM, APPLE, BOARD, BOUND, BRIEF, BURST, CHECK, CLOTH, COACH, CROWD, CRUSH, DANCE, DRIFT, DRINK, EQUAL, FIELD, FORCE, GRANT, GROAN, HOTEL, HOUSE, LAYER, LEAVE, LOCAL, METAL, MODEL, MORAL, NIGHT, PAPER, PLAIN, PLATE, POISE, ROAST, SAINT, SENSE, SHADE, SHOUT, SHRUG, SMILE, SMOKE, SOUND, SPORT, STAFF, STARE, STEAM, STORM, STOVE, STYLE, SWEAT, THUMB, TOUCH, TRUST, UNDER, VISIT, WASTE, WHEAT, WOMAN, WRECK, WRIST, YOUTH

Appendix B: Recollection and Familiarity Analyses

Separate contributions of recollection and familiarity to recognition were evaluated using the independence remember-know (IRK) procedure for each experiment (Yonelinas, 2002; Yonelinas & Jacoby, 1995). The IRK procedure estimates the contribution of recollection by the proportion of trials in which participants make "remember" (R) responses, and estimates the contribution of familiarity by the proportion of trials in which participants make "know" (K) responses, given that a remember response is not made (1-R). These estimates of recollection and familiarity were computed separately for hits and false alarms, and statistical analyses were conducted on the hit minus false alarm difference scores, which are displayed in Tables B1 and B2.

Experiment 1

To evaluate differences in recollection and familiarity, the hits minus false alarm difference scores were submitted to two separate two-tailed paired sample t tests, comparing across trial types. The analysis on the estimates of recollection revealed a significant effect of trial type, $t(47) = 4.384$, $p < .001$, $d = 0.633$, with higher estimates for incongruent (.305) than for congruent (.240) trials. The analysis on the estimates of familiarity revealed a marginal effect of trial type, $t(47) = 1.761$, $p = .085$, $d = 0.254$, with a numerical trend toward higher estimates for incongruent (.321) than for congruent (.286) trials.

Experiment 2

To evaluate differences in recollection and familiarity, the hits minus false alarm difference scores were submitted to two separate mixed-factor ANOVAs, with list type as a between-subjects factor and trial type as a within-subject factor.

Experiment 2A

The analysis on the estimates of recollection revealed a significant main effect of trial type, $F(1,46) = 11.329$, $p = .001$, $\eta_{p2} = .198$, reflecting higher recollection estimates for targets on incongruent (.323) than on congruent (.278) trials. Neither the main effect of list type nor its interaction with trial type reached significance. The analysis on the familiarity estimates revealed a main effect of trial type, $F(1,46) = 4.44$, $p = .041$, $\eta_{p2} = .088$, reflecting higher familiarity estimates for targets on incongruent (.290) than congruent (.252) trials. A main effect of list type was also observed, $F(1,46) = 6.411$, $p = .015$, $\eta_{p2} = .122$, indicating familiarity estimates were higher in the mixed (.318) than in the blocked (.223) condition. The interaction between trial type and list type was not significant.

Experiment 2B

The analysis on recollection estimates revealed an effect of trial type that approached significance, $F(1,46) = 3.32$, $p = .075$, $\eta_{p2} = .067$, with numerically higher estimates for incongruent (.380) than for congruent (.344) trials. No other analyses on the recollection or familiarity estimates yielded significant effects, all p's > .10.

Experiment 3

To evaluate differences in recollection and familiarity, the hits minus false alarms difference scores were submitted to two separate two-tailed paired sample *t* tests, comparing across trial types.

Experiment 3A

The two analyses revealed higher estimates for incongruent than for single word trials both for recollection, $t(47) = 3.913$, $p < .001$, $d = 0.565$ (.348 vs. .274), and for familiarity, $t(47) = 3.058$, $p = .004$, $d = 0.441$ (.288 vs. .217).

Experiment 3B

The analysis on recollection estimates was not significant, $t(47) < 1$. The analysis on familiarity estimates revealed an effect of trial type, $t(47) = 3.617$, $p < .001$, $d = .522$, with higher familiarity estimates for congruent trials (.303) than for single word trials (.241).

Table B1. Estimates for recollection and familiarity based on the independence remember-know procedure for Experiment 1.

	Recollection	**Familiarity**
Incongruent	.305	.321
Congruent	. 240	. 286
Difference	.065	.035

Table B2. Estimates of recollection and familiarity for Experiments 2A and 2B.

	Recollection			
	Experiment 2A		Experiment 2B	
	Mixed	**Blocked**	**Mixed**	**Blocked**
Incongruent	.322	.324	.390	.370
Congruent	.265	.291	.346	.341
Difference	.057	.033	.044	.029
	Familiarity			
	Experiment 2A		**Experiment 2B**	
	Mixed	**Blocked**	**Mixed**	**Blocked**
Incongruent	.323	.256	.368	.329
Congruent	.314	.190	.338	.267
Difference	.009	.066	.030	.062

Table B3. Estimates of recollection and familiarity for Experiments 3A and 3B.

	Recollection		
	Experiment 3A		Experiment 3B
Incongruent	.348	Congruent	.260
Single	.274	Single	.261
Difference	.074	Difference	-.001
	Familiarity		
	Experiment 3A		**Experiment 3B**
Incongruent	.288	Congruent	.303
Single	.217	Single	.241
Difference	.071	Difference	.062

Chapter 3

The Congruency Effect in Subsequent Recognition: The Role of Semantic Interference

Hanae Davis & Bruce Milliken

Abstract

Selective attention demands at the time of encoding can influence subsequent memory performance. For example, when participants name a target word that is interleaved with either a congruent (same word) or incongruent (different word) distractor, subsequent recognition performance is better for targets on formerly incongruent than congruent trials—termed the *congruency effect*. The current study examined the role of semantic interference in this effect. To address this issue, a new trial type was introduced: incongruent trials with pseudowords as distractors. These trials were designed to minimize semantic interference from the distractor on target word processing. If semantic interference is critical to the congruency effect, then this effect should not occur for these pseudoword distractor items. In Experiment 1, incongruent trials with word distractors produced the usual congruency effect, whereas incongruent trials with pseudoword distractors produced no such effect. These results suggest that semantic interference does indeed play an important role in the congruency effect. In Experiment 2, incongruent word and incongruent pseudoword trials were randomly intermixed together with congruent trials. A similar pattern to Experiment 1 emerged, with the best performance for incongruent word items and the worst performance for congruent items.

However, improved performance for incongruent word trials did appear to transfer somewhat to incongruent pseudoword trials, suggesting that expectation to encounter semantic interference on incongruent word trials plays a role in the congruency effect.

Introduction

Processing difficulties at encoding often lead to benefits in subsequent memory performance. This general observation has been reported in the context of various encoding manipulations (e.g., spacing and generation effects) and is notably characterised under the desirable difficulty principle—the idea that difficulty at encoding can lead to enhanced long-term retention (Bjork, 1994; Bjork & Bjork, 2011). Given the broad relevance of this principle, researchers have taken an interest in the specific cognitive mechanisms that underlie these effects. To this end, recent studies of encoding difficulty in relatively simple performance tasks have proven useful. Many of these studies have manipulated perceptual identification difficulty during a study phase, and measured whether and how that difficulty manipulation impacts subsequent retention (Krebs, Boehler, De Belder, & Egner, 2015; Ptok, Thomson, Humphreys, & Watter, 2019; Rosner, D'Angelo, MacLellan, & Milliken, 2015a; Rosner, Davis, & Milliken, 2015b; see also Hirshman, Trembath, & Mulligan, 1994).

One such perceptual identification manipulation introduces a selective attention requirement to the study phase task (Krebs et al., 2015; Rosner et al. 2015a). For example, Krebs et al. (2015) presented participants with male and female faces superimposed with distractor words ("man", "woman", or "house") in an initial Stroop-like task. Participants responded with the gender of the face while ignoring the distractor word, which was either congruent (male face with "man"), incongruent (male face with "woman"), or neutral (male face with "house") relative to the gender of the face. Response latencies in this task were shorter on congruent than incongruent trials, and subsequent recognition for the faces was better on previously incongruent than congruent trials. In a conceptually similar study, Rosner et al. (2015a) presented participants with two spatially interleaved words on each study trial, a red target and a green distractor. Participants named aloud the red target word. On congruent trials, the identities of the target and distractor words were the same, while on incongruent trials they were different. Naming times were faster on congruent than incongruent trials, and subsequent recognition performance was better for targets on previously incongruent than congruent trials.

These two studies suggest a potential link between high selective attention demands and encoding processes that improve subsequent memory performance. The current set of experiments aims at better understanding the processes responsible for the congruency effect on subsequent recognition first reported by Rosner et al. (2015a) – namely, superior recognition for incongruent than congruent interleaved words (Davis et al., 2019; Davis & Milliken, submitted).

One account of the congruency effect on subsequent recognition derives from the conflict monitoring model of cognitive control (Botvinick et al., 2001; see also Verguts & Notebaert, 2009). According to this account, the detection of response conflict on incongruent trials drives the upregulation of cognitive control mechanisms to resolve the conflict, which in turn enhances encoding of task-relevant stimulus representations. Given that upregulation of control on one trial often carries over to the next trial (e.g., Gratton, Coles, & Donchin, 1992), we expected the congruency effect to be sensitive to encoding context. However, examination of this prediction (Davis, Rosner, D’Angelo, MacLellan,

& Milliken, 2019) revealed neither an effect of proportion congruency nor a difference between mixed and blocked list contexts. These results argue against the idea that the congruency effect on subsequent recognition reflects an adaptation to response conflict as envisioned in the conflict monitoring model.

Although the congruency effect appears not to reflect an adaptation to response conflict, it could instead reflect an adaptation to perceptual interference. To address this possibility, Davis et al. (2019) presented a group of participants with congruent items intermixed with single word items in a first phase, and then tested recognition in a following test phase. Importantly, recognition was better for targets from congruent items than single word items. As neither congruent nor single word items contain competing identities, superior recognition for targets from congruent items appears to be related to the perceptual challenge of identifying one of two identical interleaved words on congruent trials. In other words, some form of adaptation to perceptual encoding difficulty rather than to response conflict appears to contribute to the congruency effect in subsequent recognition.[1]

At the same time, Davis et al. (2019) also included conditions that allowed a contrast between incongruent and single word conditions. Importantly, the recognition benefit for incongruent trials relative to single word trials was larger than the benefit for congruent trials relative to single word trials. This result also might be attributed to an adaptation to perceptual encoding difficulty—two different interleaved words might be more difficult to parse into separate target and distractor objects than two identical words. However, this result is also consistent with the idea that some form of semantic interference introduced by interleaving words with competing identities is critical to the congruency effect in subsequent recognition. The idea that semantic interference from competing target and distractor items contributes to the congruency effect in subsequent recognition has yet to be explored.

In line with this idea, Ptok et al. (2019) forwarded the idea that memory enhancements due to processing difficulty depend critically on semantic categorization. Their stage-specific account of desirable difficulty highlighted the utility of analyzing difficulty manipulations in terms of the stage of processing at which additional encoding is promoted. Namely, the authors proposed that an encoding manipulation that focuses additional processing at the semantic stage, as opposed to either the perception or response selection stage, would reliably lead to a benefit in subsequent memory performance. If semantic interference results in additional semantic processing at encoding, then semantic interference could well play a critical role in the enhanced memory performance for incongruent trials that characterizes the congruency effect in subsequent recognition.

The current study examined the specific role of semantic interference in the congruency effect. To do this, we modified the original design (Rosner et al., 2015a) by changing the distractor word from a real word to a pseudoword. Pseudowords are pronounceable nonwords: letter strings that can be readily named but contain no inherent semantic information (e.g., BLANE). Pseudoword distractors on incongruent trials may trigger perceptual interference in a comparable manner to real word distractors on incongruent trials, and this should be indexed by slower naming latencies relative to congruent trials. However, pseudoword distractors cannot elicit semantic interference since they have no inherent meaning. Critically, if the original congruency effect in recognition hinges on distinct *semantic* information from incongruent distractor words triggering additional encoding of the target, then this effect should not occur for targets encoded with pseudoword distractors.

Experiment 1 presented incongruent and congruent trials intermixed in an incidental study phase, where the incongruent distractors were pseudowords for one group of participants and real words for the other group. All participants were then given a surprise recognition task. We predicted that the incongruency benefit in recognition ought to be smaller—if not eliminated—for incongruent targets with pseudoword distractors than for incongruent targets with word distractors. Experiment 2 presented congruent, incongruent word, and incongruent pseudoword trials intermixed for all participants, to examine the influence of study list context on the recognition results observed in Experiment 1.

Experiment 1

Method

Participants

Forty participants from the McMaster University student pool provided informed consent and completed Experiment 1 for course credit or monetary compensation ($10.00). Participants (34 females) had a mean age of 18.6 years (SD = 1.72 years), spoke fluent English, and had either normal or corrected-to-normal vision. The general protocol used in this and all subsequent experiments was approved by the McMaster Research Ethics Board.

Apparatus and Stimuli

The stimuli in the study phase consisted of two interleaved letter strings presented in the centre of the screen against a black background (see Figure 1). One letter string was red and the other was green. On congruent trials, the red and green letter strings were the same; on incongruent trials they were different. Each letter string subtended 0.8° of visual angle vertically and 5.9° horizontally, and the two letter strings together measured 1.0° vertically and 6.5° horizontally. The red letter string appeared an equal number of times above or below the green letter string for both congruent and incongruent trial types. The stimuli in the test phase consisted of a single red word presented in the centre of the screen against a black background. The experiment used 360 words that were all high frequency five letter nouns (Kuçera & Francis, 1967; see Appendix A).

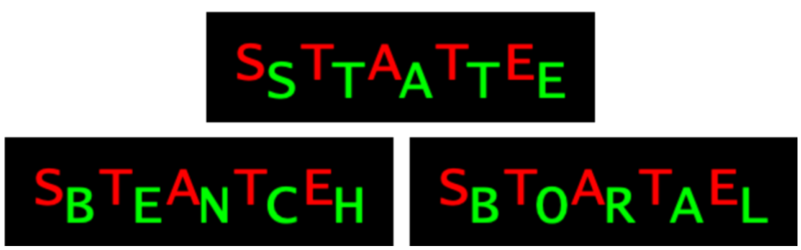

Figure 1: Stimuli used in Experiments 1 and 2; congruent (top), incongruent with word distractor (bottom left), and incongruent with pseudoword distractor (bottom right).

The experimental program was run on a Mac Mini computer using Psychopy© experimental software (Pierce, 2007; 2009). The stimuli were displayed on a 24-in BENQ LED monitor, and responses were made using a microphone and keyboard. Participants sat approximately 50 cm from the monitor and participated individually.

Procedure

There were three phases in this experiment: an incidental study phase, a math distractor task phase, and a recognition test phase. Participants were randomly assigned to one of two groups (word/pseudoword) before the first phase.

The incidental study phase consisted of 120 trials. Each trial began with a central fixation cross for 2000 ms, after which participants were presented with a red target word spatially interleaved with a green distractor word/pseudoword for 1000 ms; participants read aloud the target word as quickly and accurately as possible. There was a 500 ms blank screen before the next trial began. Response latencies were recorded from the onset of the interleaved stimuli to the onset of the vocal response.

Participants in both groups were presented with an equal number of congruent (target and distractor were identical) and incongruent (target and distractor were different) trials randomly intermixed. The two groups differed only in the distractors presented in the study phase: in the word group, the distractor was a word (Rosner et al, 2015a; Davis et al., 2019); in the pseudoword group, the distractor was a pseudoword (see Design for how these were generated). Participants in both groups were instructed to ignore the distractors. After participants made a verbal response on each trial, the experimenter, seated in the same room, coded the response as correct, incorrect, or a spoil, by pressing the “1”, “2”, or “3” key, respectively, on the keyboard. A response was coded as incorrect if the participant named or began to name a word other than the target. A response was coded as a spoil if the experimenter suspected that a noise other than a naming response (e.g., coughing) set off the microphone. A ten-minute distractor task followed the study phase. The distractor task required participants to complete a series of arithmetic problems involving basic math operations (e.g., addition, multiplication) on two and three-digit numbers.

The last phase was a surprise recognition test, which began with the provision of detailed instructions both verbally from the experimenter and visually written on the screen. These instructions included an explanation of the distinction between “remembering” and “knowing” (Rajaram, 1993). All stimuli in the recognition test phase were single red words. Half of these were target words from the study phase, whereas the other half were new words. The distractor words from the study phase were not re-presented in the test phase. There were 240 test trials in total: 60 old targets from previously congruent trials, 60 old targets from previously incongruent trials, and 120 new word trials.

Each trial began with a 2000 ms central fixation cross. A red word was then presented centrally with two prompt words, “OLD” and “NEW”, presented in white in the bottom left and bottom right of the screen, respectively. The prompt words were presented in the same font as the red word. These stimuli remained on the screen until participants responded by pressing either the “A” key, if they thought the red word was “old”, or the “L” key if they thought the red word was “new.” When an “old” response was made, the “OLD” and “NEW” prompt words were replaced by “TYPE A” and “TYPE B”, respectively. Participants made a remember/know response by indicating whether their “old” response was based on a Type A memory (a feeling of remembering) or a Type B memory (a feeling of knowing; McCabe & Geraci, 2009). There was a 150 ms blank screen before the next trial began. The experimenter was seated in the room with the participant.

Design

There were two key independent variables in this experiment. For the distractor-type variable, distractors were either real words (word group) or pronounceable nonwords (pseudoword group). For the congruency variable, targets and distractors were identical in the congruent condition and different in the incongruent condition.

Three hundred and sixty unique words were used in the experiment (see Appendix A). Sixty of these words were used to create pseudowords that served as incongruent distractors in the pseudoword group. These pseudowords were manually generated by the first author by replacing the first letter in a word, and in a few cases an additional letter, with a different consonant, while ensuring it was still pronounceable. Pseudo-homophones were avoided, and an effort was made to use a wide range of onset letters. The same 60 pseudowords were used for all participants in the pseudoword group. The remaining 300 words were randomly divided into five lists of 60 words, and were assigned to the following trial types, counterbalanced across participants: study-list congruent, study-list incongruent, old incongruent distractor (only relevant for the word group), and new (combined two lists = 120 words). This counterbalancing scheme ensured that the five lists were assigned to these trial types an equal number of times across participants.

Results

Response times (RTs) for correct trials from the study phase were submitted to a non-recursive outlier procedure with moving criterion (Van Selst & Jolicoeur, 1994). This procedure eliminated 2.8% of observations from further analyses. In addition, words that were named incorrectly in the study phase were excluded from analysis of the test phase, which eliminated 0.40% of congruent trials and 0.75% of incongruent trials. For the study phase analysis, the mean of the remaining RTs and error rates for each condition were computed for each participant. For the test phase analysis, proportions of "old" responses for old and new items were transformed into *d'* values (a measure of recognition sensitivity) and beta (a measure of bias). These dependent variables were entered into the analyses of variance described below. The remember/know data from the test phase were gathered primarily for exploratory purposes and are presented in Appendix B for the interested reader.

Study Phase

Mean correct RTs and error rates were submitted to two separate mixed factor ANOVAs that treated distractor-type group (word/pseudoword) as a between-subjects factor and congruency (congruent/incongruent) as a within-subject factor (see Table 1).

Table 1: Mean response times at study in Experiment 1 (arcsine transformed error rates in parentheses; see text).

	Congruent	Incongruent
Word Group	671 (.006)	835 (.059)
Pseudoword Group	630 (.000)	781 (.038)

Participants were significantly slower for incongruent (808 ms) than for congruent (651 ms) trials, $F(1,38) = 186.08$, $p < .001$, $n_p^2 = .830$. There was no effect of distractor-type and no interaction between distractor type and congruency, *p*'s > .10.

The analysis of naming errors was conducted on arcsine-transformed error rates, to accommodate the large number of extremely low error rates. There were more errors committed on incongruent (.048) than on congruent (.003) trials, $F(1,38) = 17.64$, $p < .001$, $n_p^2 = .17$. There was neither a main effect of distractor-type nor a congruency by distractor-type interaction, *p*'s > .10.

Test Phase

Mean proportions of "old" responses, averaged across participants, are displayed in Table 2, and mean *d'* values are displayed in Figure 2.

Table 2: Mean proportion of "old" responses to old and new test items in Experiment 1.

	Old		New
	Congruent	Incongruent	
Word Group	.624	.713	.242
Pseudoword Group	.591	.605	.219

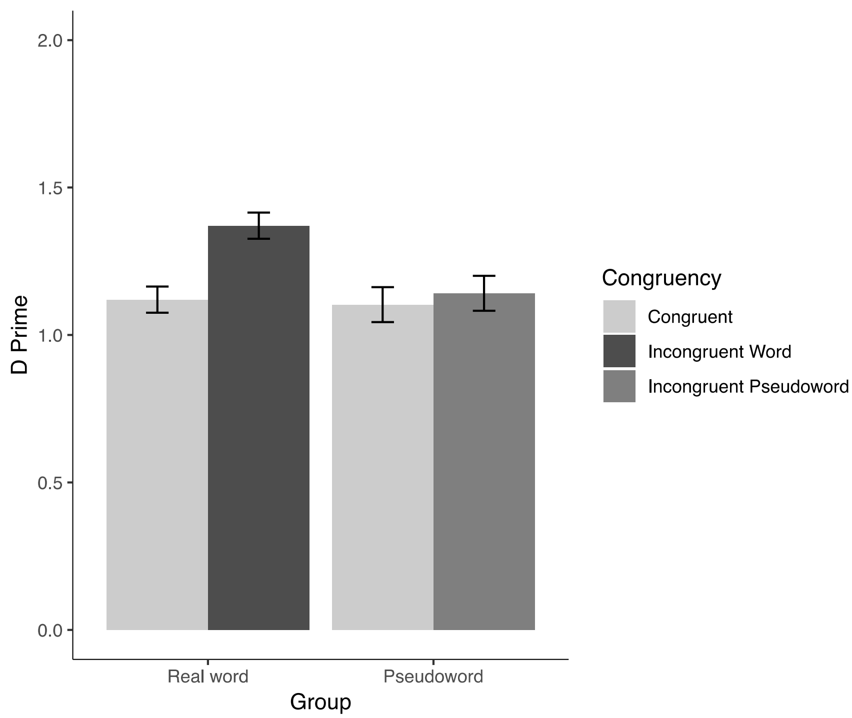

Figure 2: Mean *d'* values in Experiment 1. Error bars in this and all subsequent figures are the SEM with between-subjects variance removed (Cousineau, 2005; Morey, 2008).

D prime and beta values were submitted to the same mixed factor ANOVA as the study phase RTs. These analyses treated distractor-type group (word/pseudoword) as a between-subjects factor and congruency (congruent/incongruent) as a within-subject factor.

Recognition sensitivity was higher for targets on formerly incongruent (1.26) than on formally congruent (1.11) trials, $F(1,38) = 7.64$, $p = .009$, $n_p^2 = .167$. This effect of congruency was different for the two distractor-type groups, $F(1,38) = 4.12$, $p = .049$, $n_p^2 = .098$. In the word group, sensitivity was higher for incongruent (1.37) than for congruent (1.12) targets, $t(19) = 4.00$, $p < .001$, $d = 0.894$, replicating the incongruency benefit reported previously (Rosner et al., 2015a; Davis et al., 2019). In contrast, in the pseudoword group, sensitivity did not differ for incongruent (1.14) and congruent (1.10) trials, $t(19) = 0.46$, $p = .652$, $d = 0.103$. The analysis of beta revealed no significant effects, p's > .100.

Discussion

Experiment 1 examined the role of semantic interference in the congruency effect in subsequent recognition first reported by Rosner et al. (2015a). The results of the word distractor-type group replicated previous findings with significantly better recognition for incongruent than congruent items. In contrast, the results of the pseudoword group offered a different and informative result. Specifically, in the pseudoword group, there was no difference in recognition sensitivity between congruent and incongruent items. Interestingly, however, the slowing of response times on incongruent trials in the study phase was comparable across the two distractor-type groups. This result implies that naming times are a poor index for the enhanced encoding that improves recognition for incongruent trials in the word group. Slowed naming responses sometimes are, and other times are not, accompanied by improved recognition for incongruent trials. The congruency effect in subsequent recognition for spatially interleaved word stimuli appears to depend specifically on processes elicited by semantic interference between target and distractor items.

Experiment 2

In Experiment 1, the incongruency benefit depended critically on the lexicality of the incongruent distractors. This result suggests that semantic interference was, in some way, responsible for more robust encoding on incongruent than congruent trials. However, given the list-wise presentation of distractor type (word versus pseudoword), it is not clear whether this effect results from online encoding of each incongruent item as it occurs, or instead from an encoding strategy for all incongruent items presented in a uniform context.

Experiment 2 examined the word–pseudoword distractor difference within a single list to avoid any list-wide processing strategy differences between the two distractor types. All participants experienced both word and pseudoword incongruent trials, along with congruent trials, in the same list context. As such, they were unable to predict which trial type they would encounter before the trial was presented.

Method

Participants

Thirty-six participants from the same pool completed Experiment 2 for course credit. Participants (30 females) had a mean age of 18.2 years (SD = 0.62 years), spoke fluent English, and had either normal or corrected-to-normal vision.

Apparatus, Stimuli, and Procedure

The apparatus, stimuli, and procedure were the same as Experiment 1 with one exception. Incongruent distractor types were randomly intermixed within participants in Experiment 2 rather than presented to separate groups of participants as in Experiment 1. As such, all participants were presented with all three trial types in a single randomly intermixed study list: congruent, incongruent word distractor, and incongruent pseudoword distractor trials. Participants were not told beforehand about the distinction between the two incongruent trial types.

Design

The design differed from that of Experiment 1 in the counterbalancing method. For Experiment 2, each of the five 60-item word lists used in Experiment 1 was halved to generate a total of ten lists of 30 items. Nine of these lists were selected to be used in the current experiment. Similarly, the 60-item pseudoword word list was divided into two lists of 30 pseudowords.

Of the 120 study trials in this experiment, 60 were congruent trials, 30 were incongruent word trials, and 30 were incongruent pseudoword trials. Two of the nine 30-word lists were combined and assigned to congruent trials, one list was assigned to targets on incongruent word trials, and another list was assigned to targets on incongruent pseudoword trials. A further one list was assigned to distractors on incongruent word trials. And last, the four remaining word lists were combined to generate the 120 new trials presented at test. All word lists were assigned to the different trial types an equal number of times across participants. For distractors on incongruent pseudoword trials, either of the two 30-item pseudoword lists was assigned and each list was assigned an equal number of times across participants.

Results

Response times for correct trials from the study phase were submitted to the same outlier removal procedure as Experiment 1 (Van Selst & Jolicoeur, 1994), eliminating 2.4% of observations from further analyses. In addition, targets on 0.9% of incongruent word trials and 0.7% of incongruent pseudoword trials were named incorrectly and consequently removed from the recognition analyses. For the study phase analysis, the means of the remaining RTs and error rates were computed for each participant. For the test phase analysis, proportions of "old" responses for old and new items were transformed into *d'* and beta values. These dependent variables were entered into the analyses of variance described below. The remember/know data from the test phase are reported in Appendix B.

Study Phase

Mean correct RTs and naming errors were submitted to two separate repeated measures ANOVAs that treated congruency (congruent/incongruent word/incongruent pseudoword) as a within-subject factor. Mean RTs and naming errors, collapsed across participants, are displayed in Table 3.

Table 3: Mean response times at study in Experiment 2 (arcsine transformed error rates in parentheses).

Congruent	Incongruent Word	Incongruent Pseudoword
670 (.000)	823 (.038)	824 (.036)

In the analysis of RTs, there was an effect of congruency, $F(2,70) = 101.70$, $p < .001$, $n_p^2 = .810$. Fisher's LSD post-hoc comparisons revealed this was driven by faster responses on congruent trials (670 ms) than on both incongruent word trials (823 ms), $t(35) = 11.50$, $p < .001$, $g = 1.29$, and incongruent pseudoword trials (824 ms), $t(35) = 11.59$, $p < .001$, $g = 1.15$. There was no statistical difference between RTs on incongruent word trials and incongruent pseudoword trials, $t(35) = 0.092$, $p = .928$, $g = 0.009$.

The analysis of naming errors was conducted on the arcsine transformed error rates to accommodate the high number of extremely low error rates. There was an effect of congruency, $F(2,70) = 4.514$, $p = .014$, $n_p^2 = .229$. Fisher's LSD post-hoc comparisons showed numerical trends toward more errors committed on incongruent word (.038) and incongruent pseudoword (.036) trials than on congruent trials (.00); $t(35) = 1.840$, $p = .074$, $g = 0.578$, $t(35) = 1.727$, $p = .093$, $g = 0.670$, respectively.

Test Phase

To evaluate recognition performance, separate repeated measures ANOVAs were conducted on *d'* (sensitivity) and beta (bias) values, again treating congruency as a within-subject factor. Mean *d'* values, averaged across participants, are displayed in Figure 3, while mean proportions of "old" responses are displayed in Table 4.

Table 4: Mean proportions of "old" responses to old and new test items in Experiment 2.

Old			New
Congruent	Incongruent Word	Incongruent Pseudoword	
.627	.699	.666	.216

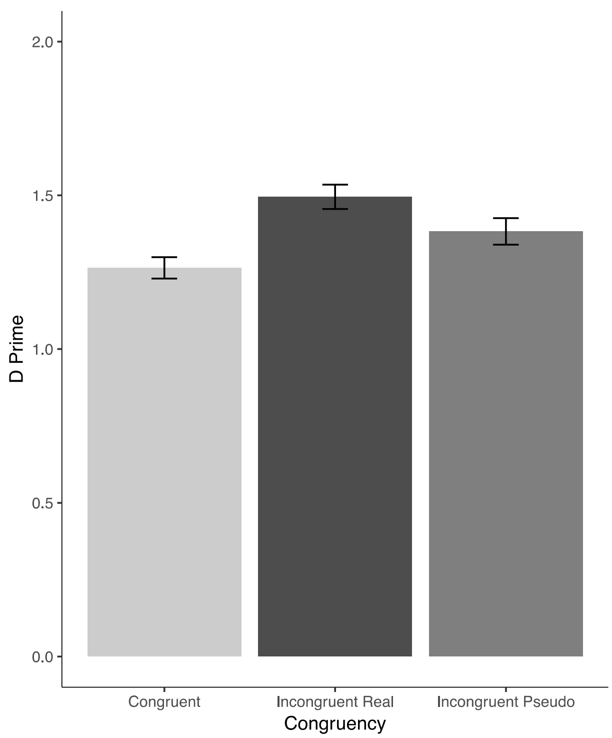

Figure 3: Mean *d'* values in Experiment 2.

The analysis of *d'* revealed a significant effect of congruency, $F(2,70) = 8.64$, $p = .001$, $n_p^2 = .386$. Fisher's LSD post-hoc comparisons revealed better memory sensitivity for targets on incongruent word trials (1.50) than on congruent trials (1.26), $t(35) = 4.00$, $p < .001$, $g = 0.466$, replicating the congruency effect observed for the word distractor group in Experiment 1. Interestingly, memory sensitivity was also better for targets on incongruent pseudoword trials (1.38) than on congruent trials, $t(35) = 2.06$, $p = .047$, $g = 0.245$. Finally, there was a non-significant numerical trend toward better sensitivity on incongruent word trials than on incongruent pseudoword trials, $t(35) = 1.950$, $p = .059$, $g = 0.241$.

The analysis of beta also revealed an effect of congruency, $F(2, 70) = 6.977$, $p = .002$, $n_p^2 = .403$. Fisher's LSD post-hoc comparisons revealed a more conservative response criterion for congruent (1.74) than for incongruent (1.61) word trials, $t(35) = 3.244$, $p = .002$, $g = 0.090$. The difference between congruent and incongruent pseudoword trials (1.66) approached significance, $t(35) = 1.961$, $p = .058$, $g = 0.059$.

Discussion

Experiment 2 examined whether the elimination of the incongruency benefit in the pseudoword group in Experiment 1 depended on the presentation of pseudoword and word distractors in separate list contexts. To this end, all three trial types were intermixed in the same study list for all participants. The typical incongruency benefit in recognition was observed for incongruent word trials compared to congruent trials. Interestingly, a recognition benefit for incongruent pseudoword trials relative to congruent trials was also observed.

This result suggests that the list-wide context in which pseudoword distractor items occurs may influence how they are encoded. In particular, similarity between word and pseudoword distractor trials may result in similar encoding processes being engaged for these two trial types on at least some occasions when they are randomly intermixed in a single list. In this manner, encoding processes that are responsive to semantic interference may transfer to items in which no actual resolution of semantic interference is required.

General Discussion

Several studies in recent years have focused on perceptual desirable difficulties, namely benefits in memory due to increased difficulty of perceptual identification (Krebs et al, 2015; Ptok et al., 2019; Rosner et al., 2015a; Rosner et al., 2015b; see also Hirshman, Trembath, & Mulligan, 1994). Most relevant to the current study, the congruency effect in subsequent recognition (Krebs et al., 2015; Rosner et al., 2015a) was examined primarily from the perspective that interference in general drives upregulations in processing for target items in selective attention tasks, which in turn enhances memory performance. In the task variant where target and distractor words are spatially interleaved, the interference on incongruent trials could have a perceptual, semantic, or response basis. Previous work has either remained neutral on the level of interference that underlies the congruency effect in recognition (Rosner et al., 2015a), or has instantiated a variant of the manipulation that aimed at influencing perceptual processing (Davis et al., 2019). To this point, no study has examined the semantic contribution to this effect.

Might co-activation of competing semantic representations drive the up-regulation in encoding that produces the congruency effect in subsequent recognition?

To evaluate this possibility, a new type of incongruent trial was generated. For incongruent pseudoword trials, the distractor that was spatially interleaved with the target word was a pseudoword rather than a word. These incongruent pseudoword trials contain minimal semantic interference, while still inducing a significant amount of interference at the perceptual level.

In Experiment 1, incongruent distractor type was manipulated between groups. Participants in the word and pseudoword distractor groups were equally slow to name incongruent targets relative to congruent targets. However, an incongruency benefit in subsequent recognition was observed only in the word group. In Experiment 2, congruent, incongruent word, and incongruent pseudoword trials were intermixed randomly within the same study list for all participants. Again, naming times were no different for incongruent word and pseudoword trials, and both were slower than for congruent trials. In contrast to Experiment 1, recognition was superior for both incongruent word targets and pseudoword targets than for congruent targets.

Semantic Processing as a Source of Perceptual Desirable Difficulty

Taken together, the basic congruency effect in subsequent recognition—incongruent word trials vs congruent trials—appears to be influenced by the lexicality of the distractors on incongruent trials. Experiment 1 demonstrated this effect clearly by exhibiting no recognition benefit when all incongruent trials in a list had pseudowords as distractors. This result suggests that when processing verbal stimuli in a selective attention task, competition between two semantic representations—perhaps separate from perceptual interference—helps drive the processing adjustments that underlie better memory for incongruent targets.

This idea is in line with accounts forwarded for other desirable difficulty effects, which point to higher-order representations as the locus of enhanced encoding for the difficult trial type. Trembath, Hirshman, and Mulligan (1994) proposed a compensatory processing account to explain the perceptual interference effect—superior memory for single words presented briefly and pattern-masked than for words left unmasked—originally reported by Nairne (1998). This account suggests that the pattern mask renders the visual information insufficient to arrive at the correct word identity, leading to greater activation of higher-order non-visual information associated with the masked word (including semantic information) to compensate for the partial bottom-up percept. This greater higher-order activation in turn enhances memory performance for the masked words relative to unmasked words.

Ptok et al. (2019) forwarded a stage-specific control account to explain why difficulty manipulations that focus processing resources at semantic categorization reliably leads to desirable difficulty effects whereas those that focus processing at response selection do not. The former type promotes additional semantic processing of task-relevant representations (i.e., targets), which in turn enhances memory performance. The latter type promotes additional processing of the response tied to the task-relevant representation, which is not the to-be-remembered information for later retrieval. Experiment 1 in the present study demonstrated that an incongruency benefit is observed when interference from the distractor is both perceptual and semantic in nature, but not when it was only perceptual. This result supports the notion that perceptual identification manipulations reliably enhance memory when they direct processing resources toward resolving semantic interference.

Experiment 2 offered a qualification to the pattern observed in Experiment 1 by suggesting that pseudoword distractors can in fact enhance encoding when intermixed with word distractors, but perhaps not to the same degree. When both incongruent trial types were encountered in the same list, participants in Experiment 2 may have treated pseudoword distractors similarly to word distractors on at least some trials (MacLellan, Shore & Milliken, 2018). This transfer of processing across similar trial types may have produced processing of target words on incongruent pseudoword trials that was comparable to incongruent word trials—potentially via enhanced encoding of semantic information due to the illusory perception of impending semantic interference. However, if the treatment of distractors was entirely determined by list context, we ought to have observed equivalent memory performance across the two incongruent trial types. The trend toward higher sensitivity for incongruent word trials than for incongruent pseudoword trials here suggests that some caution is needed with respect to the role of list context; some aspect of processing on incongruent trials may still be determined by semantic interference itself, independent of list context.

Not Time-on-Task

Although the congruency effect in subsequent recognition has been examined primarily from a cognitive control perspective (Rosner et al., 2015a; Davis et al., 2019), there remains an alternative account of this effect that is substantially less theoretically interesting. This time-on-task view (see Cooper & Pantle, 1967) suggests that incongruent selective attention items are remembered better simply because participants spend more time processing them, as indexed by slower naming times in the study phase. Previous studies have used post hoc analyses to argue against the time-on-task account. For example, Rosner et al. (2015a) noted that recognition sensitivity was better for a subset of incongruent items that were named more quickly than a subset of slowly named congruent items. The results from the present study offer a more compelling argument against a simple time-on-task explanation for congruency effects on long-term memory.

Specifically, there is a clear dissociation between the pattern of performance in naming times and subsequent memory in Experiment 1. The difference in naming times between congruent and incongruent trials was observed for both the word and pseudoword groups, but only the word group exhibited a memory benefit for incongruent targets. Therefore, longer stimulus processing reflected in slowed naming times does not itself capture the processing responsible for the congruency effect. We suggest instead that this recognition benefit for incongruent targets is driven by activation of higher-order semantic representations that may or may not influence naming times.

Conclusion

The present study examined the processes that produce better recognition for targets with high selective attention demands relative to those with lower selective attention demands. The results reported here suggest that this memory effect depends on the activation of semantic representations for the distractor that compete with those for the target. This semantic interference on incongruent trials may then upregulate semantic processing of the target, which in turn results in improved recognition performance. Whether this upregulation in semantic processing is controlled entirely by online semantic interference, or by contextual factors that predict the need to resolve semantic interference, is an area that merits further study.

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Footnotes

Note 1. Although it is possible that the recognition benefit for congruent targets relative to single word targets reported by Davis et al. (2019) was driven by the presence of two identical representations of the word rather than perceptual interference, it seems unlikely. Perceptual fluency via identical word representations has been shown to hinder rather than to promote additional encoding of the target word in a comparable paradigm (Rosner, López-Benitez, D'Angelo, Thomson, Milliken, 2018; Collins, Rosner, & Milliken, 2018). This paradigm entailed a prime-probe procedure, where prime and probe words were presented in temporal succession and participants were asked to name the probe word aloud. The two words matched in identity on repeated trials and were different on non-repeated trials. Mirroring the results from the selective attention procedure (Rosner et al., 2015a; Davis et al., 2019), naming times were faster on repeated trials (akin to congruent trials) but subsequent recognition performance was better for targets from non-repeated trials (akin to incongruent trials). Therefore, the fluency afforded by the repeated presentation of two words (in temporal succession in the prime-probe procedure, or concurrently in the selective attention procedure) is unlikely to promote additional learning of the target.

Appendix A: Word Lists

Word list 1: ANGER, CAUSE, UPPER, BELLY, HONEY, PLANE, DOUBT, REALM, SUGAR, DRIVE, SMART, MIDST, ESSAY, STATE, EMPTY, FRONT, DANCE, TRACK, CLOUD, METAL, FENCE, DRAMA, MINOR, SEVEN, CROWN, SERVE, GIANT, LOBBY, GUILT, SCALE, BURST, PUPIL, SPLIT, GRACE, FRAME, SIXTY, INNER, SLEEP, FLUID, OPERA, FEVER, ENEMY, STILL, EVENT, EXTRA, CLOTH, THICK, BRASS, PLAIN, MERCY, ROUTE, ASIDE, HURRY, SHEET, LEMON, REACH, DRAFT, MORAL, SUITE, CABIN

Word list 2: SMELL, SOLID, CLAIM, FORCE, INPUT, EIGHT, OTHER, STICK, TRIAL, UNITY, SOUTH, MARCH, RADAR, PAUSE, TITLE, STYLE, BENCH, YOUTH, PHONE, ENTRY, DREAM, COAST, STUFF, SNAKE, SKILL, SHAME, APRIL, PARTY, PANIC, SMALL, UNCLE, YIELD, TRACE, STOCK, SCENE, GLORY, ISSUE, CHOSE, GLASS, GUEST, QUIET, DRAIN, THING, ONSET, OWNER, FIELD, POINT, PRINT, STERN, LAUGH, QUEEN, WORST, INDEX, TEETH, CHART, CLEAN, BASES, NOVEL, TODAY, LIMIT

Word list 3: DAIRY, CLERK, NIGHT, CLASS, HOUSE, PIECE, PENNY, SHEEP, WHEEL, CRASH, SHORT, CHIEF, LUNCH, POUND, DRINK, MAGIC, WAGON, BRICK, STORY, TREAT, RIGHT, SPITE, FLOOD, DRIFT, GUARD, STORM, SHOCK, GUESS, PLANT, SWEET, BIRTH, ALERT, SPACE, FLOOR, CRIME, THREE, BOOTS, THIRD, COVER, WRONG, RANCH, DOZEN, DAILY, AGENT, IMAGE, ORDER, SPEED, VOICE, TRUCK, TOUCH, LEAST, STAND, TREND, BREAD, ACTOR, PRICE, PLATE, SCOPE, RIVER, CLOCK

Word list 4: LODGE, SOUND, BROWN, WOUND, BLAME, MASON, COURT, RIDGE, CHARM, CHILD, HOTEL, SHIFT, JUDGE, KNIFE, THROW, FLASH, BLOCK, MOUNT, STAKE, UNDER, SWIFT, SKIRT, SPOKE, CURVE, TOUGH, SLIDE, OCEAN, DROVE, MOTEL, QUICK, NORTH, MIGHT, PRIZE, WIDOW, SCREW, LOOSE, ROUND, ROUGH, MONEY, VERSE, WATCH, TRAIL, WOMAN, DELAY, WORLD, CYCLE, PAINT, STORE, SWING, ERROR, BREAK, TRUST, PIANO, STAGE, EARTH, SMOKE, FIFTY, STRIP, COUNT, BLIND

Word list 5: NOISE, AWARD, SHEAR, TRUTH, SENSE, SHOOT, STAFF, SHARP, GREEN, NOBLE, THEME, SHORE, TRAIN, VALUE, TOOTH, CLOSE, BRAIN, WATER, BAKER, MEANS, RANGE, DRESS, TABLE, PITCH, SAUCE, DRILL, PRIOR, STEEL, COACH, CHAIR, SHADE, GROUP, BOARD, MAJOR, BASIS, MUSIC, MOTOR, PANEL, MOUTH, LOCAL, PORCH, TRADE, SMILE, WHILE, MODEL, PEACE, ANGEL, MOVIE, DEPTH, PHASE, DOING, HEART, SMITH, FIGHT, GUIDE, FOCUS, START, TOAST, GRAIN, GRASS

Pseudoword list: BENSE, BEVED, BIVAN, BORAL, BRASP, CAGAN, DANAL, DOMMY, DORTE, DOSSE, DRASS, FANDY, FOISE, FORSO, GEMON, GIRUS,

GOKER, GROST, HAPSE, HAVEL, JETCH, KATIN, KEDGE, KENOR, KIDER, KINEN, LAINY, LANSY, LERGE, LERUM, MAZOR, MEPOT, MEPTA, MESIN, MOOTH, NADGE, NANIA, NIARY, NOLLY, NULCH, PELIC, PLICE, POVER, RADET, RASTE, ROGMA, SACON, SAIRY, SECOR, SIDGE, SINCH, SLIFF, TERTH, TRAND, TROSE, TUNCH, WARGE, WONOR, YOOSE, ZANOR

Root words for pseudowords (in corresponding order): TENSE, FEVER, DIVAN, CORAL, GRASP, PAGAN, CANAL, TOMMY, FORTE, POSSE, BRASS, DANDY, POISE, TORSO, LEMON, VIRUS, POKER, FROST, LAPSE, LABEL, FETCH, SATIN, WEDGE, TENOR, RIDER, LINEN, DAIRY, PANSY, SERGE, SERUM, RAZOR, DEPOT, SEPTA, RESIN, TOOTH, BADGE, MANIA, DIARY, MOLLY, MULCH, RELIC, SLICE, LOVER, CADET, PASTE, DOGMA, BACON, FAIRY, DECOR, RIDGE, PINCH, CLIFF, BERTH, BRAND, PROSE, BUNCH, BARGE, DONOR, GOOSE, MANOR

Appendix B: Recollection and Familiarity Estimates

Unique contributions of recollection and familiarity processes to recognition were evaluated using the independence remember–know (IRK) procedure for both experiments (Yonelinas, 2002; Yonelinas & Jacoby, 1995). The IRK procedure estimates the contribution of recollection by the proportion of trials in which participants make "remember" (R) responses, and estimates the contribution of familiarity by the proportion of trials in which participants make "know" (K) responses, given that a remember response is not made (1-R). These estimates of recollection and familiarity were computed separately for hits *("old" responses to old items)* and false alarms *("old" responses to new items)*, and analyses were conducted on the hit minus false alarm difference scores. Recollection and familiarity estimates are displayed in Table B1 for Experiment 1 and in Table B2 for Experiment 2.

Experiment 1

To evaluate differences in recollection and familiarity, hit minus false alarm difference scores were submitted to two separate mixed factor ANOVAs that treated distractor-type group (word/pseudoword) as a between-subjects variable and congruency (congruent/incongruent) as a within-subject factor.

The analysis of recollection estimates revealed a main effect of congruency, with significantly higher estimates for incongruent trials (.268) than for congruent trials (.230), $F(1,38) = 4.393$, $p = .043$, $n_p^2 = .104$. The main effect of distractor-type group was not significant, but trended toward higher recollection estimates in the word group (.286) than in the pseudoword group (.212), $F(1,38) = 2.547$, $p = .119$, $n_p^2 = .063$. The congruency by distractor-type interaction was also not significant, $F(1, 38) = 1.800$, $p = .188$, $n_p^2 = .045$, but trended toward higher estimates for incongruent (.317) than for congruent (.254) trials in the word group, $t(19) = 2.296$, $p = .033$, $d = 0.513$, but no difference in the pseudoword group (.219 vs .206; $t(19) = 0.569$, $p = .576$, $d = 0.127$).

The analysis of familiarity estimates revealed no significant effects. However, there was a trend toward a main effect of congruency, with higher estimates for incongruent trials (.252) than for congruent trials (.223), $F(1,38) = 2.066$, $p = .159$, $n_p^2 = .052$. The congruency by distractor-type group interaction trended toward higher estimates for incongruent trials (.262) than for congruent trials (.208) in the word group, $t(19) = 2.217$, $p = .039$, $d = 0.496$, but there was no difference in the pseudoword group (.241 vs .238; $t(19) = 0.120$, $p = .906$, $d = 0.027$; $F(1, 38) = 1.555$, p = .220, $n_p^2 = .039$).

Figure B1: Recollection and familiarity estimates in Experiment 1.

	Word Group		Pseudoword Group	
	Congruent	Incongruent	Congruent	Incongruent
Recollection	.254	.318	.206	.219
Familiarity	.208	.262	.238	.241

Experiment 2

Recollection and familiarity estimates were submitted to two separate repeated measures ANOVAs that treated congruency (congruent/incongruent word/incongruent pseudoword) as a within-subject factor. Analysis of recollection estimates revealed an effect of congruency, $F(2,70) = 3.917$, $p = .024$, $n_p^2 = .212$. Fisher's LSD post-hoc comparisons revealed a trend toward higher estimates for incongruent word trials (.313) than for congruent trials (.267; $t(35) = 1.956$, $p = .058$, $g = 0.246$), and no difference between incongruent pseudoword trials (.292) and congruent trials or between word and pseudoword trials, p's > .100.

Analysis of familiarity estimates also revealed an effect of congruency, $F(2,70) = 3.597$, $p = .032$, $n_p^2 = .268$, which was driven by higher estimates for targets on incongruent word trials (.317) than on congruent trials (.249), $t(35) = 2.877$, $p = .007$, $g = 0.444$. Estimates were not different between congruent and incongruent pseudoword trials nor between word and pseudoword trials, p's > .100.

Figure B2: Recollection and familiarity estimates in Experiment 2.

	Congruent	Incongruent Word	Incongruent Pseudoword
Recollection	.267	.313	.292
Familiarity	.249	.317	.288

Chapter 4

Comparing Selective Attention Effects on Encoding in Recognition and Free Recall

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Abstract

Recent work has demonstrated better recognition for targets encoded incidentally on incongruent than on congruent selective attention trials (Krebs, Boehler, de Belder, & Egner, 2015; Rosner, D'Angelo, MacLellan, & Milliken, 2015). This effect points to a possible link between selective attention demands and memory encoding. The present study examined whether this effect also occurs in free recall. Memory performance was indeed better on incongruent than congruent trials both in recognition and in free recall. However, in free recall, this effect was limited to the first of multiple study-test blocks. These results are discussed in relation to processing differences between recognition and recall, and to the cause of the congruency effect itself.

Introduction

Increased processing difficulty during encoding is at times associated with improved memory performance (Bjork 1994). In addition to seminal examples such as the generation effect (Slameka & Graf, 1978), a variety of perceptual processing difficulties also fit this principle. Words that are pattern masked are better remembered than words left unmasked (Nairne, 1988), and words with unusual orthography are better remembered than words with common orthography (Zechmeister, 1969). Of particular interest here, two recent studies reported that items encoded incidentally with high selective attention demands were recognized better than items encoded with low selective attention demands (Krebs et al., 2015; Rosner et al., 2015).

Krebs et al. (2015) used a face-word Stroop-like task that asked participants to identify the gender of target faces overlaid with the distractor word “male” or “female.” On a following surprise recognition test, there were more high-confidence hits for faces formerly presented on incongruent than on congruent trials. Rosner et al. (2015) reported a similar result. They presented two spatially interleaved words, a red target and a green distractor, on each study trial. The target and distractor words matched in identity on congruent trials and mismatched on incongruent trials. Subsequent recognition memory was better for incongruent than for congruent targets.

A subsequent study showed the interleaved words congruency effect to be remarkably insensitive to study list context—it did not vary with changes in proportion congruent in the study phase, and was equally large for blocked and intermixed study lists (Davis, Rosner, D’Angelo, MacLellan, & Milliken, 2019). Moreover, trial-to-trial study list transitions did not reveal changes in recognition that might be predicted by transient shifts in cognitive control (e.g., Botvinick et al., 2001). All told, these results ruled out the idea that superior recognition for incongruent items stems from transient up-regulation of cognitive control in response to interference, and pointed to a need for further study of this effect.

To that end, all prior studies of the interleaved words congruency effect have used a recognition memory task. Here, we examined whether this effect would also occur in a free recall task. Recognition and recall are widely thought to involve different processes (Kintsch, 1970; McDaniel & Bugg, 2008; Tversky, 1973), and therefore do not always produce identical effects across tasks. For example, high frequency words are often better recalled than low frequency words, whereas low frequency words are recognized better than high frequency words (Glanzer & Bowles, 1976; Kintsch, 1970). Intentional encoding and list organization also tend to aid recall more than recognition (Kintsch, 1970; Tversky, 1973). Of most importance here, processing difficulty at study generally produces more robust effects in recognition than recall (McDaniel & Bugg, 2008). Thus, better memory for incongruent than congruent targets may be observed in recognition but not in free recall. Perhaps the learning consequences of processing adaptations at encoding that underlie this effect may be observed in the former memory task but not in the latter. We examined this issue in three experiments here.

Experiments 1A and 1B

In Experiments 1A and 1B, participants named one of two interleaved words in four unique study lists of 32 items. Following each of these study lists, participants completed either a recognition test (Experiment 1A) or a recall test (Experiment 1B).

Method

Participants

Twenty-four individuals (21 females; mean age = 18.75 years, SD = 1.48) participated in Experiment 1A, and two groups of 24 individuals (40 females; mean age = 18.51 years, SD = 0.69) participated in Experiment 1B. Participants were recruited through the McMaster University student pool, had normal or corrected-to-normal vision, spoke English fluently, and received course credit for participation.

Apparatus & Stimuli

The stimuli were identical to those used by Rosner et al. (2015; see Figure 1); a red target word interleaved with a green distractor. Each word subtended 0.8° vertically and 5.9° horizontally, and together the two words measured 1.0° by 6.5°. The stimuli were created using 384 five-letter high frequency nouns (Kuçera & Francis, 1967; see Appendix A for list design details). The program was run using Psychopy (Pierce, 2007) on a Dell computer, and stimuli were displayed on a 24-inch BENQ LED monitor. Participants were tested individually, sat approximately 50 cm from the monitor, and responded using a microphone and keyboard.

***Figure 1*:** Stimuli used in Experiments 1A, 1B, and 2 for incongruent (top left), congruent (top right) and single word (bottom) trials.

Procedure

Experiments 1A and 1B each consisted of four unique study-test blocks. Participants were informed of the repeated study-test structure and the nature of the memory task prior to the first study phase. The memory task was recognition in Experiment 1A, and free recall in Experiment 1B.

Experiment 1A. Each study phase trial presented a red target word interleaved with a green distractor word (see Figure 1). The target appeared either above the distractor or below, and this factor was counterbalanced across all conditions. On congruent trials the red and green words had the same identity, whereas on incongruent trials they had different identities. Participants read the target aloud as quickly and accurately as possible. Study trials began with a central fixation cross for 2000 ms, followed by the interleaved words for 1000 ms. A blank screen followed offset of the words, during which the experimenter coded the vocal response for accuracy. Each study phase consisted of 32 experimental trials, with equal proportions of congruent and incongruent trials intermixed. There were 4 filler trials at the beginning and end of each study list; data from these trials were not analyzed. Following each study phase, participants counted backwards aloud by 3 or 4 from a pre-assigned number (e.g., 357) for 10 seconds.

Each test phase consisted of 64 recognition trials. Half of the test items were seen in the immediately preceding study phase ("old") and half were new items. Half of both old and new items were congruent and half were incongruent. Old target words were re-presented with the same distractor words they were paired with at study[7]. A trial began with a central fixation cross for 2000 ms, followed by a test item that remained on screen until response. Participants made an old/new response to each item, and 'old' responses were followed by a remember/know judgment. Remembering and knowing were assigned to Type A and Type B responses, respectively (Rajaram, 1993; McCabe & Geraci, 2009).

Experiment 1B. The procedure was similar to Experiment 1A with two exceptions: (1) the memory task was free recall; and (2) two groups of participants were tested. The control group was informed simply that they would engage in a free recall task following each study phase. The relational instruction group was asked additionally to pay attention to semantic relations across adjacent targets in the study phase, because it could help their subsequent recall performance. This instructional manipulation was exploratory, and did not influence recall on its own or in interaction with other factors. In each test phase, participants were given five minutes to type on a computer keyboard as

[7] The reinstatement of distractors at test introduces a potential source of false recognition for both hits and false alarms; processing fluency is higher for congruent than incongruent items. Importantly, Experiment 2 in Rosner et al. (2015) and other unpublished results from our lab demonstrate that this false recognition effect at test influences performance separately from the congruency effect at study; that is, robust congruency effects also occur when distractors are not re-instated at test.

many of the target words as they could recall from the immediately preceding study phase.

Results

Study Phases

RTs on correct study phase trials were submitted to an outlier procedure that removed 2.9% and 2.3% of observations from the analyses of Experiments 1A and 1B, respectively (Van Selst & Jolicoeur, 1994)[8]. Mean RTs in Experiment 1A were submitted to a repeated-measures ANOVA that treated congruency (congruent/incongruent) and block (1-4) as within-subject factors. Mean naming RTs in Experiment 1B were submitted to a mixed factorial ANOVA that treated group (control/relational instructions) as a between-subjects factor and congruency (congruent/incongruent) and block (1-4) as within-subject factors. Mean correct RTs and errors are presented in Table 1.

[8] A technical problem resulted in empty RT cells for four participants in Experiment 1A and one participant in Experiment 1B; their data were excluded from the study phase analyses, but were included in test phase analyses.

Table 1: Mean RTs and error rates in the study phase in Experiments 1A and 1B

		Response Times (ms)				**Naming Errors (%)**
		Block 1	Block 2	Block 3	Block 4	
1A						
	Incongruent	821	759	770	736	0.4
	Congruent	670	629	654	644	1.6
	Difference	151	130	116	92	
1B: Control						
	Incongruent	839	828	844	828	0.5
	Congruent	666	684	705	712	2.5
	Difference	173	144	139	116	
1B: Relational						
	Incongruent	797	831	833	774	0.1
	Congruent	647	690	708	691	1.5
	Difference	150	141	125	83	

Responses were faster on congruent than incongruent trials in Experiment 1A (649 vs 772 ms), $F(1,19) = 66.018$, $p < .001$, $n_p^2 = .776$, and in Experiment 1B (688 vs 821 ms), $F(1,45) = 467.327$, $p < .001$, $n_p^2 = .912$. There was also a significant interaction between congruency and block in both experiments, $F(3,57) = 3.662$, $p = .017$, $n_p^2 = .391$ and $F(3,135) = 9.71$, $p < .001$, $n_p^2 = .428$, respectively. Inspection of Table 1 indicates that the congruency effect decreased across blocks in both experiments.

Two additional effects were significant in Experiment 1B. First, there was a significant main effect of block, $F(3,135) = 5.971$, $p < .001$, $n_p^2 = .312$). Post hoc comparisons revealed that RTs were faster in block 1 than block 3, $t(46) = 4.15$, $p < .001$, $d = .605$, but no other comparison reached significance (Bonferroni-corrected $\alpha = .008$). Second, there was a significant group by block interaction, $F(3,135) = 2.827$, $p = .041$, $n_p^2 = .208$. This effect appears to be driven by faster RTs in the relational instructions group than the control group in blocks 1 and 4, but not blocks 2 and 3.

Test Phases

Targets named incorrectly in the study phases were excluded from analysis of memory performance (0.4% and 0.3% of congruent trials, and 1.6% and 2.2% of incongruent trials, in Experiments 1A and 1B, respectively). Remember/know data in Experiment 1A were gathered for exploratory purposes and are presented in Appendix B.

Experiment 1A. Proportion 'old' responses were submitted to a repeated measures ANOVA that treated congruency (congruent/incongruent), item status (old/new), and block (1-4) as within-subject factors. Proportions of 'old' responses are shown in Table 2, and corrected hit rates (hits minus false alarms) are shown in Figure 2.

***Table 2*:** Proportion 'old' responses to old and new items in Experiment 1A

	Block 1		Block 2		Block 3		Block 4	
	Old	New	Old	New	Old	New	Old	New
Incongruent	.74	.13	.72	.13	.73	.11	.68	.15
Congruent	.74	.16	.70	.16	.71	.17	.65	.15

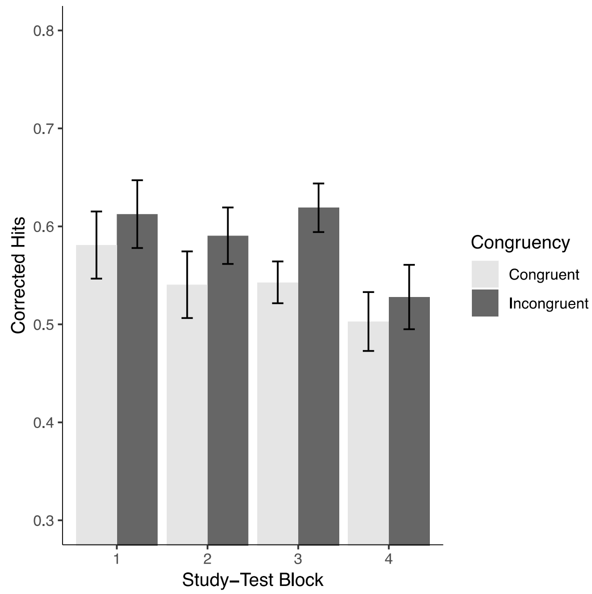

Figure 2: Corrected hit rates in Experiment 1A. Error bars in this and all subsequent figures depict the SEM with between-subjects variability removed (Morey, 2008).

Proportion judged 'old' was higher for old (.71) than for new (.14) items, $F(1, 23) = 474.47$, $p < .001$, $n_p^2 = .954$. More important, the interaction between item status and congruency approached significance, $F(1, 23) = 4.08$, $p = .055$, $n_p^2 = .151$. Echoing prior studies, recognition sensitivity (hits – false alarms) was higher for incongruent than for congruent items.

The only other effect that approached significance was the item status by block interaction, $F(3,69) = 2.592$, $p = .060$, $n_p^2 = .252$. Recognition sensitivity was best in block 1 and worst in block 4, perhaps reflecting a buildup of proactive interference across the experiment (see Figure 2).

Experiment 1B. Proportions of correctly recalled items were submitted to a 2x2x4 mixed factorial ANOVA. Intrusions (i.e., items studied in one block and recalled in a later block) were rare (1.0%) and not included in the analysis. Mean recall performance for all conditions is displayed in Table 3.

Table 3: Proportion correct recalled for control and relational instruction groups in Experiment 1B.

		Block 1	Block 2	Block 3	Block 4
Control Group					
	Incongruent	.266	.293	.360	.306
	Congruent	.196	.253	.310	.318
Relational Group					
	Incongruent	.255	.254	.252	.280
	Congruent	.165	.279	.248	.297

There were main effects of both block, $F(3,138) = 9.191$, $p < .001$, $n_p^2 = .364$, and congruency, $F(1,46) = 4.02$, $p = .050$, $n_p^2 = .080$, as well as a significant congruency by block interaction, $F(3,138) = 3.407$, $p = .019$, $n_p^2 = .210$. Separate analyses of the congruency effect for each block revealed that proportion recalled was higher for incongruent (.26) than congruent (.18) items in block 1, $t(47) = 4.065$, $p < .001$, $d = .587$, but not in any other block (all p's > .10; see Figure 3).

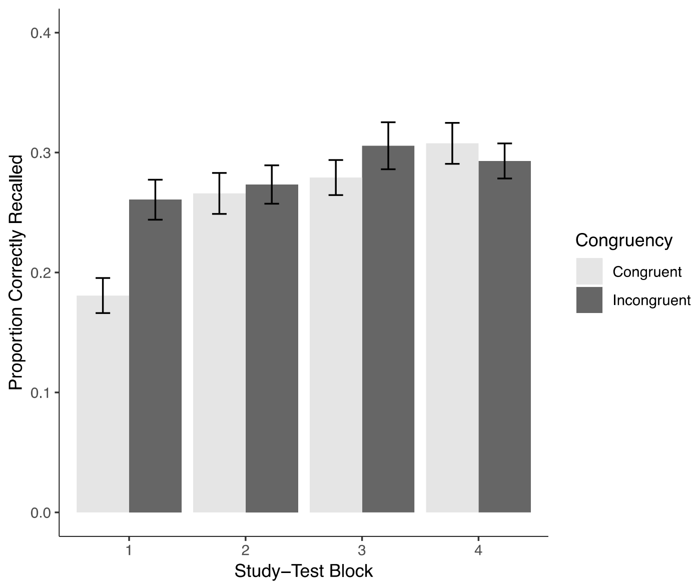

***Figure 3*:** Proportion correctly recalled in Experiment 1B, collapsed across control and relational instruction groups.

Discussion

In Experiment 1A, recognition was superior for incongruent than for congruent items. Although this effect only approached significance here, a similar effect has been observed in several prior studies (Rosner et al., 2015; Davis et al., 2019). Notably, this effect did not vary across blocks. In Experiment 1B, recall was superior for incongruent than congruent items, but only in the first study-test block. We conclude that an incongruency benefit can indeed be observed in both memory tasks, but that the effect is less stable across repeated study-test blocks in recall than in recognition.

Experiment 2

Experiment 2 examined this task comparison again to determine whether the results described above are robust to a change in method. In Experiment 2, incongruent trials were compared to single word trials rather than to congruent trials (see also Davis et al., 2019).

Method

Participants

Forty-six individuals (33 females; mean age = 18.72, SD = 0.96) from the McMaster University student pool participated in Experiment 2 for course credit. All participants had normal or corrected-to-normal vision, and spoke English fluently.

Apparatus & Stimuli

These were identical to Experiments 1A and 1B with one exception. The congruent words of Experiments 1A and 1B were replaced with single red words.

Procedure

The procedure was identical to Experiments 1A and 1B with the following exceptions. Participants were randomly assigned to either a recognition group or a recall group. In the study phases, a red word appeared on its own (single word trials) or interleaved with a green distractor (incongruent trials).

Results

Study Phases

The outlier analysis eliminated 2.4% of observations from further analyses[9]. Mean RTs were submitted to repeated-measures ANOVAs separately for each task that treated congruency (single word/incongruent) and block (1-4) as within-subject factors. Mean RTs and error percentages are presented in Table 4.

Table 4: Mean RTs and error percentages during study for recognition and recall groups in Experiment 2.

		Response Times (ms)				**Naming Errors (%)**
		Block 1	Block 2	Block 3	Block 4	
Recognition						
	Incongruent	801	784	784	765	1.8
	Single Word	597	633	640	634	0.3
	Difference	204	151	144	131	
Free Recall						
	Incongruent	823	829	832	820	2.9
	Single Word	610	661	671	665	0.4
	Difference	213	168	161	155	

Responses were faster on single word than incongruent trials in both the recognition group (626 vs 784 ms), $F(1,22) = 147.503$, $p < .001$, $n_p^2 = .870$, and the recall group (652 vs 826 ms), $F(1,21) = 130.092$, $p < .001$, $n_p^2 = .861$. There was also a

[9] A technical problem resulted in empty RT cells for one participant; their data were excluded from analyses of naming RTs but were included in analyses of memory performance.

significant congruency by block interaction in both groups, $F(3,66) = 6.523$, $p < .001$, $n_p^2 = .441$ and $F(3,63) = 2.988$, $p = .038$, $n_p^2 = .292$, respectively. As in prior experiments, the congruency effect diminished across blocks for both groups (see Table 4).

Test Phases

Words that were incorrectly named in the study phases were excluded from test phase analyses (0.3% of single word trials, 2.3% of incongruent trials). Remember/know data from the recognition group are presented in Appendix B.

Recognition Group. Mean proportion 'old' responses were submitted to a repeated measures ANOVA that treated congruency (single word/incongruent), item status (old/new), and block (1-4) as within-subject factors. Proportion old responses are displayed in Table 5, and corrected hit rates are displayed in Figure 4.

Table 5. Proportion 'old' responses to old and new items for the recognition group in Experiment 2

	Block 1		Block 2		Block 3		Block 4	
	Old	New	Old	New	Old	New	Old	New
Incongruent	.84	.12	.77	.13	.78	.13	.76	.14
Single	.82	.15	.77	.21	.73	.18	.76	.16

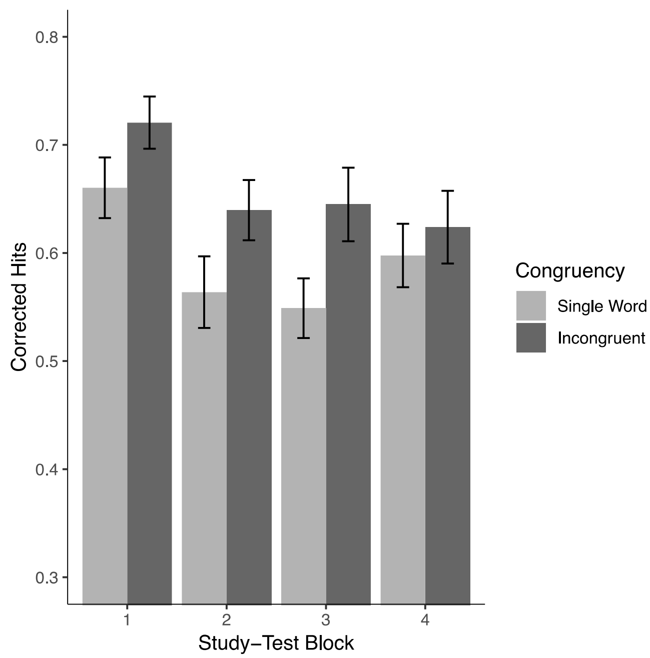

Figure 4: Corrected hits for the recognition group in Experiment 2

Participants responded ‘old’ more often for old (.78) than for new (.15) items, $F(1, 22) = 521.95$, $p < .001$, $n_p^2 = .960$. More important, the interaction between item status and congruency was significant, $F(1, 22) = 9.694$, $p = .005$, $n_p^2 = .306$. The hit–false alarm difference was larger for incongruent than for congruent items (see Figure 4).

The only other significant effect in the analysis was the interaction between item status and block, $F(3,66) = 3.93$, $p = .012$, $n_p^2 = .502$. Post-hoc pairwise comparisons of hit minus false alarm difference scores revealed that the item status effect was larger in block 1 than block 2, $t(22) = 3.16$, $p = .004$, $d = .659$, and block 3, $t(22) = 3.36$, $p = .003$, $d = .700$, (Bonferroni corrected $\alpha = .008$).

Recall Group. The proportions of correctly recalled items in each condition were submitted to a repeated-measures ANOVA with congruency and block as within-subject factors (see Figure 5). The frequency of intrusions was low (1.1%) and intrusions were not included in analyses.

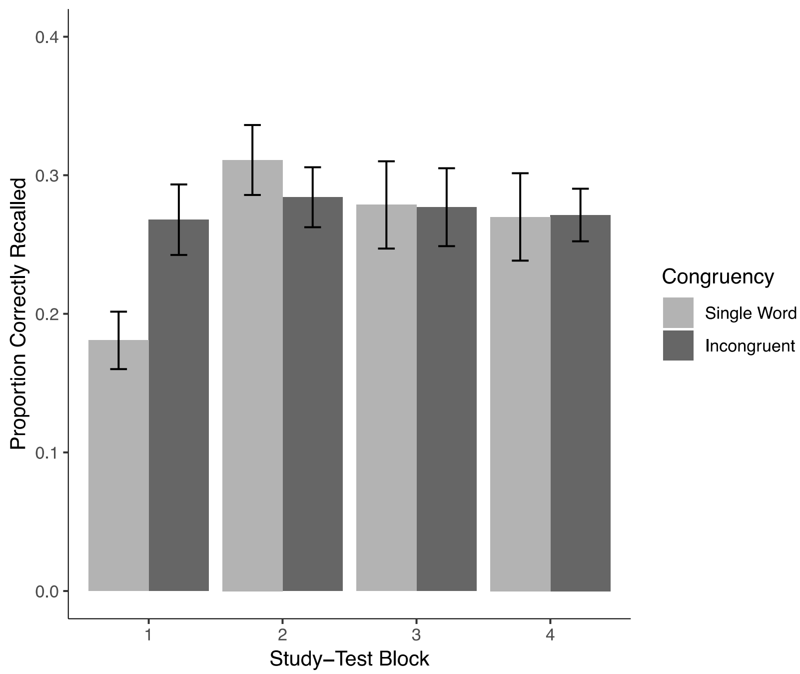

Figure 5**:** Proportion correctly recalled for the recall group in Experiment 2

In contrast to the recognition group, the main effect of congruency was not significant, $F(1,22) = 0.939$, $p = .343$. The interaction between congruency and block also failed to reach significance, $F(3,66) = 2.123$, $p = .106$, $n_p^2 = .243$. However, to determine whether the key results of Experiment 1B were reproduced here, we analyzed the results separately by block. Proportion recalled was higher for incongruent (.27) than single word trials (.18) in block 1, $t(22) = 3.271$, $p = .003$, $d = 0.682$, but not for the other three blocks (all p's > .10; see Figure 5).

Discussion

The results from the recognition and recall groups corresponded closely to those observed in Experiments 1A and 1B. Whereas recognition sensitivity was higher for incongruent than single word trials generally, recall performance was better for incongruent trials only in block 1. The consistency in this pattern across different item type contrasts suggests that it captures a stable processing difference between recall and recognition in this paradigm.

General Discussion

This study examined whether a memory benefit for incongruent selective attention items reported previously in recognition (Davis et al., 2019; Krebs et al., 2013; Rosner et al., 2015) can also be observed in free recall (see also Muhmenthaler & Meier, 2019). As recognition and recall involve different memory processes (Kintsch, 1970; McDaniel & Bugg, 2008; Tversky, 1973), a comparison of congruency effects across these tasks holds the potential to identify which processes in particular are affected by congruency.

The recognition results of Experiments 1A and 2 offered conceptual replications of the incongruency benefit in recognition reported previously, using multiple short study-test blocks rather than a single long study-test procedure (Rosner et al., 2015; Davis et al., 2019). The recall results of Experiments 1B and 2 exhibited a more dynamic pattern than observed in recognition—superior performance for incongruent items was observed, but only in the first study-test block. These results demonstrate that the processes that produce the incongruency benefit in recognition can also contribute to free recall, but that processing contributions to recall change across study-test blocks.

One point of note is that recognition performance declined across blocks, whereas recall performance improved across blocks. The recognition result may reflect an accumulation of proactive interference. The recall result appears to be driven by an improvement for congruent/single word items across blocks, particularly between the first and second blocks. This pattern of recall performance suggests that participants may not have encoded the easier (congruent/single word) items well in block 1, but learned to encode them more effectively in subsequent blocks, thus closing the gap between performance for congruent/single word and incongruent items.

A premise that fits this dynamic pattern in recall is that intentional learning influences recall more than recognition (Kintsch, 1970; Tversky, 1973). By this view, the processes engaged at study are not necessarily *different* between the two tasks, but *additional* information encoded due to intentional learning is better captured in recall than in recognition. Hence recall of congruent/single word items improves after block 1, but recognition of congruent/single word items does not improve.

A more nuanced view may also be worth consideration. Participants can encode *different* kinds of information in anticipation for particular memory tasks for which they are preparing (Tversky, 1973). In particular, recall is enhanced by interitem organization within a list, while recognition relies on the integration of features within a studied item that aides its discrimination from other items. Furthermore, across several well-established memory effects, difficult-to-process items are thought to benefit from enhanced item encoding whereas their easy-to-process counterparts are primarily encoded via relational processing (McDaniel & Bugg, 2008; Hunt & Einstein, 1981). Together, these ideas fit the proposal that the incongruency benefit in both recognition and recall is driven primarily by enhanced item encoding for incongruent items. The more dynamic pattern in recall may be driven by increased contribution of relational encoding to performance for congruent/single word items across blocks, as recall is known to be sensitive to both item and relational influences (McDaniel & Bugg, 2008).

Conclusion

This study demonstrates that an incongruency benefit observed previously in recognition can also be observed in free recall. Moreover, the different patterns of results across blocks for the two tasks highlights the potential utility of studying this effect across tasks to better understand the processes that are influenced by increased selective attention demands during encoding.

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Appendix A: Word lists used in all experiments

Experiment 1A

The stimuli were constructed from 384 five-letter high frequency nouns (Kuçera & Francis, 1967) divided into six lists of 64 words each. The assignment of lists to three item roles (congruent, incongruent target, incongruent distractor) was counterbalanced across participants for old items and randomized across participants for new items. Lists of 64 items for each critical condition (old/new x congruent/incongruent) were split into four lists of 16 items for the four study-test blocks. Each of four study phases consisted of four filler items, 32 critical items, and four additional filler items. The filler items were drawn from a separate list of high frequency nouns and were the same for all participants. Each of four test phases consisted of the 32 critical items from the preceding study phase, and an additional 32 new items, for a total of 64 recognition trials.

Experiment 1B

The design for each of the two groups in Experiment 1B was identical to Experiment 1A with one exception. Only three of the six lists were needed for each participant, as the free recall task did not require generation of new items for the test phases.

Word List 1: ANGER, CAUSE, UPPER, BELLY, HONEY, PLANE, DOUBT, REALM, SUGAR, DRIVE, SMART, MIDST, ESSAY, STATE, EMPTY, FRONT, DANCE, TRACK, CLOUD, METAL, FENCE, DRAMA, MINOR, SEVEN, CROWN, SERVE, GIANT, LOBBY, GUILT, SCALE, BURST, PUPIL, SPLIT, GRACE, FRAME, SIXTY, INNER, SLEEP, FLUID, OPERA, FEVER, ENEMY, STILL, EVENT, EXTRA, CLOTH, THICK, BRASS, PLAIN, MERCY, ROUTE, ASIDE, HURRY, SHEET, LEMON, REACH, DRAFT, MORAL, SUITE, CABIN, JUICE, LARGE, FINAL, OLIVE

Word List 2 :SMELL, SOLID, CLAIM, FORCE, INPUT, EIGHT, OTHER, STICK, TRIAL, UNITY, SOUTH, MARCH, RADAR, PAUSE, TITLE, STYLE, BENCH, YOUTH, PHONE, ENTRY, DREAM, COAST, STUFF, SNAKE, SKILL, SHAME, APRIL, PARTY, PANIC, SMALL, UNCLE, YIELD, TRACE, STOCK, SCENE, GLORY, ISSUE, CHOSE, GLASS, GUEST, QUIET, DRAIN, THING, ONSET, OWNER, FIELD, POINT, PRINT, STERN, LAUGH, QUEEN, WORST, INDEX, TEETH, CHART, CLEAN, BASES, NOVEL, TODAY, LIMIT, OFTEN, UNION, TOWER, WRITE

Word List 3: DAIRY, CLERK, NIGHT, CLASS, HOUSE, PIECE, PENNY, SHEEP, WHEEL, CRASH, SHORT, CHIEF, LUNCH, POUND, DRINK, MAGIC, WAGON, BRICK, STORY, TREAT, RIGHT, SPITE, FLOOD, DRIFT, GUARD, STORM, SHOCK, GUESS, PLANT, SWEET, BIRTH, ALERT, SPACE, FLOOR, CRIME, THREE, BOOTS, THIRD, COVER, WRONG, RANCH, DOZEN, DAILY, AGENT, IMAGE, ORDER, SPEED, VOICE, TRUCK, TOUCH, LEAST, STAND, TREND, BREAD, ACTOR, PRICE, PLATE, SCOPE, RIVER, CLOCK, GREAT, TAKEN, FIRST, WHOLE

Word List 4: LODGE, SOUND, BROWN, WOUND, BLAME, MASON, COURT, RIDGE, CHARM, CHILD, HOTEL, SHIFT, JUDGE, KNIFE, THROW, FLASH, BLOCK, MOUNT, STAKE, UNDER, SWIFT, SKIRT, SPOKE, CURVE, TOUGH, SLIDE, OCEAN, DROVE, MOTEL, QUICK, NORTH, MIGHT, PRIZE, WIDOW, SCREW, LOOSE, ROUND, ROUGH, MONEY, VERSE, WATCH, TRAIL, WOMAN, DELAY, WORLD, CYCLE, PAINT, STORE, SWING, ERROR, BREAK, TRUST, PIANO, STAGE, EARTH, SMOKE, FIFTY, STRIP, COUNT, BLIND, CIVIL, PLACE, YOUNG, FRESH

Word List 5: NOISE, AWARD, SHEAR, TRUTH, SENSE, SHOOT, STAFF, SHARP, GREEN, NOBLE, THEME, SHORE, TRAIN, VALUE, TOOTH, CLOSE, BRAIN, WATER, BAKER, MEANS, RANGE, DRESS, TABLE, PITCH, SAUCE, DRILL, PRIOR, STEEL, COACH, CHAIR, SHADE, GROUP, BOARD, MAJOR, BASIS, MUSIC, MOTOR, PANEL, MOUTH, LOCAL, PORCH, TRADE, SMILE, WHILE, MODEL, PEACE, ANGEL, MOVIE, DEPTH, PHASE, DOING, HEART, SMITH, FIGHT, GUIDE, FOCUS, START, TOAST, GRAIN, GRASS, ABOVE, ALONE, HAPPY, HEARD

Word List 6: CRAFT, SPELL, PROOF, SHIRT, BRIEF, PRESS, STONE, CHEST, EQUAL, CROSS, SCORE, ADULT, OFFER, TASTE, GRADE, LABEL, ANGLE, LIGHT, SHELL, CROWD, PRIDE, SHARE, PILOT, PAPER, VISIT, PRIME, MERIT, BRUSH, SLOPE, WASTE, RATIO, CHECK, MATCH, BRIDE, SIGHT, THANK, BEACH, CRACK, CHAIN, TOTAL, LEAVE, SHAPE, SWEAT, STUDY, RADIO, BOUND, FRUIT, HORSE, GRANT, CHEEK, IDEAL, LEVEL, CREAM, REBEL, CATCH, CHASE, WHITE, MONTH, FAINT, GROSS, BELOW, WORTH, HUMAN, CLEAR

Appendix B: Recollection and Familiarity Analyses

Separate contributions of recollection and familiarity to recognition were evaluated using the independence remember–know (IRK) procedure for Experiments 1A and 2 (Yonelinas, 2002). The IRK procedure estimates the contribution of recollection by the proportion of trials in which participants make "remember" (R) responses, and estimates the contribution of familiarity by the proportion of trials in which participants make "know" (K) responses given that a remember response is not made (1-R). These recollection and familiarity estimates were computed separately for hits and false alarms, and statistical analyses were conducted on the hit minus false alarm difference scores, which are displayed in Table B1. In Experiment 1A, recollection estimates were significantly higher for incongruent (.406) than for congruent (.347) trials, $t(23) = 2.1142$, $p = .045$, $d = 0.432$, whereas familiarity estimates did not differ across conditions. Similarly, in Experiment 2, recollection estimates were significantly higher for incongruent (.493) than for single word (.426) trials, $t(22) = 3.286$, $p = .003$, $d = 0.685$, whereas familiarity estimates did not differ across conditions.

Table B1: Recollection and familiarity estimates for the recognition test phases of Experiment 1A and the recognition group of Experiment 2, collapsed across block.

		Recollection	**Familiarity**
Experiment 1A	Incongruent	.406	.416
	Congruent	.347	.395
Experiment 2 (Recognition Group)	Incongruent	.493	.440
	Single Words	.426	.419

Chapter 5: General Discussion

The notion of a link between attention and subsequent remembering is an intuitive one. In the field of cognitive psychology, however, the domains of attention and memory have matured largely independently of each other. On this particular topic, the domain of attention often focuses on adjustments in online processes that support stimulus perception and response, while the domain of memory focuses on stimulus encoding and retrieval processes that support retention. Although this separation between domains has been convention for most of the field's history, the last few decades have seen increased study of these two domains in tandem. This thesis aligns with this trend toward studying attention and memory together. In particular, the research reported here focuses on perceptual desirable difficulties—manipulations that render initial perception difficult but benefit long-term retention. More specifically, these studies examined the cognitive processes that underlie better memory for items with high selective attention demands than for those with low selective attention demands.

The Congruency Effect

In a typical selective attention task, participants are instructed to focus on some features or stimuli (target information) while ignoring others (distractor information). When these two types of information mismatch, or are incongruent with each other, selective attention demands are described to be high. When they match, or are congruent with each other, selective attention demands are described to be low. These different demands across trial types are typically indexed by slower response latencies (RTs) to target information on incongruent trials. Recent work has extended this procedure by adding a memory test phase to a selective attention study phase. The study phase presented congruent and incongruent trials comprised of spatially interleaved target and distractor words, and the test phase examined the memory consequences of differential selective attention demands at study (Rosner et al., 2015). Recognition memory for target words was better on incongruent trials than on congruent trials. This finding—termed the *congruency effect*—served as the empirical focus of this thesis.

Conflict monitoring and cognitive control

A particularly influential framework for studying transient shifts in selective attention processes is the conflict monitoring model of cognitive control (Botvinick et al., 2001). This neurocognitive model outlines how the detection of response conflict can produce an upregulation of control processes to resolve response conflict and support efficient task performance. These upregulations in control were later proposed to have learning consequences that could enhance memory for task-relevant information (Verguts & Notebaert, 2008; 2009). These ideas motivated the experiments included in Chapter 2 of this thesis. This study aimed to evaluate the conflict monitoring framework as it applies to the *memory* consequences of selective attention demands at study.

Chapter 2 first examined the potential influence of list context—the context in which incongruent trials were presented—to see whether the congruency effect in memory depended critically on transient shifts in selective attention demands, similar to congruency effects in online performance (Davis et al., 2020). Three variants of list context were examined: proportion congruent (low versus high proportion congruent), mixed versus blocked lists (congruent and incongruent intermixed or blocked), and trial-by-trial sequences (prior trial congruency and current trial congruency). The congruency effect did not vary as a function of proportion congruent, and was no different for mixed and blocked lists. Although there was a small effect of prior trial congruency on current trial congruency, this effect was not in line with predictions derived from the conflict monitoring model. Taken together, the results suggest that processes outlined in the conflict monitoring model are unlikely to be responsible for the congruency effect in memory.

This chapter also dissociated the potentially separate roles of response conflict and perceptual interference in the congruency effect. Incongruent trials possess both response conflict (different responses for target and distractor words) and perceptual interference (the general perceptual challenge of interleaved stimuli), while congruent trials possess only the latter. To dissociate these two factors, these two trial types were compared to single red words across two separate groups of participants. Both congruent and incongruent trial types produced a recognition benefit relative to the single word baseline, but the effect was larger for incongruent trials. Therefore, while perceptual interference does appear to contribute to the congruency effect, it may not account for the entire effect.

The findings from this chapter challenged us to think about the idea of processing difficulty influencing encoding more broadly, rather than focusing on response conflict as had been done in the online performance literature. If not response conflict, what unique property of incongruent interleaved stimuli triggers the processing adjustments that promote differential encoding of target information? This question was addressed in Chapter 3.

Semantic Interference in a Perceptually Based Task

A closer examination of our stimuli pointed us to another locus of congruency, termed semantic interference, to describe the conflict that arises from the co-presentation of words with distinct meanings. Incongruent trials may give rise to the co-activation of two distinct semantic representations, and verbalizing the correct response may require the selection of the target representation over that of the distractor. Thus, semantic congruency may influence encoding on incongruent trials by promoting greater processing of semantic representations associated with the target word.

Chapter 3 introduced a new type of incongruent trial—pseudoword-distractor trials—which enabled us to isolate the potential contribution of semantic interference from that of perceptual interference (Davis & Milliken, in prep). Pseudoword-distractor trials consisted of a real word target (as in all prior experiments) interleaved with a pseudoword distractor. Pseudowords are pronounceable non-words that contain minimal semantic information (e.g., BLANE). These pseudoword-distractor trials are similar perceptually to word-distractor incongruent trials (both involve interleaved letter strings), but are different semantically (the distractor is meaningful only for word-distractor trials). When compared to congruent trials, a congruency effect was observed for word-distractor incongruent trials but not for pseudoword-distractor incongruent trials. This novel result pointed to the importance of distractor interference at the semantic level to observe the congruency effect.

Both perceptual and semantic interference seem to contribute to the congruency effect (for a variant of this task wherein response interference is critical, see Muhmentaler and Meier, 2019). First, processing difficulty in the form of increased perceptual demands appears to influence recognition. The degree of spatial interleaving (Experiment 2, Rosner et al., 2015) and interleaving in and of itself (Experiment 3 in Chapter 2, Davis et al., 2020) influenced the magnitude of the congruency effect. Second, interference at the level of meaning also influences subsequent recognition. When the distractor on incongruent trials is a pseudoword, recognition performance is equivalent between congruent and incongruent targets (Experiment 1 in Chapter 3; but see Experiment 2).

The idea that semantic interference promotes additional semantic processing to benefit memory is relatively intuitive—"deeper" processing, especially by attending to meaning, is well-known to support long-term retention (Craik & Lockhart, 1972). More interestingly, perceptual interference may also promote additional semantic processing. As discussed in Chapter 1, the idea that perceptual difficulties can trigger additional processing of conceptual information is shared across multiple memory effects (e.g., for the perceptual interference effect, see Hirshman et al., 1994; for the orthographic distinctiveness effect, see Hunt & Elliot, 1980). This idea also fits with the empirical work in this thesis and offers a more parsimonious explanation than proposing separate perceptual and semantic effects on memory in this task. The locus of the encoding benefit for incongruent trials may thus be at the level of semantic representations.

Congruency Effects in Free Recall

Chapter 4 addressed whether the congruency effect can be observed in a retrieval task other than recognition—namely, free recall (Davis & Milliken, under revision). A core tenet of the memory domain is that task performance is jointly influenced by processes active at encoding and at retrieval—the concept of transfer appropriate processing (Morris, Bransford, & Franks, 1977). Our research question was therefore important for two reasons: first, observing the congruency effect in free recall would indicate how robust it is to different retrieval conditions; second, comparing performance across memory tasks that involve different cognitive processes could shed light on those responsible for the congruency effect. The experiments in this chapter compared recognition and free recall performance under highly similar conditions, to better understand the encoding and retrieval processes that underlie the congruency effect.

Across two demonstrations that used a multiple study-test block procedure, we demonstrated a congruency effect in both recognition and recall. The first set of experiments intermixed congruent and incongruent trials, while the second experiment intermixed single word and incongruent trials, and the patterns were comparable across the two trial type pairings. In recognition, memory was better overall for incongruent than congruent trials, and better for incongruent than single word trials, replicating previous results using a single study-test procedure (Rosner et al., 2015; Davis et al., 2020). In recall, however, the congruency effect varied systematically across study-test block. A clear congruency effect was observed in the first block, but not in any of the subsequent blocks. This finding was driven largely by an improvement for congruent and single word items across blocks, particularly between the first and second blocks. These results suggest that participants were initially unprepared to process the relatively easy items in a way that facilitated later retrieval, perhaps in the service of processing the more difficult incongruent items. After the first block, however, participants appeared to learn to process easy items more effectively, thereby closing the gap between congruent/single word and incongruent item performance from the second block onward.

One interpretation of this set of findings rests on the item versus relational information distinction (Hunt & Einstein, 1981; Hunt & McDaniel, 1993; McDaniel & Bugg, 2008; see also McDaniel, Einstein, & Lollis, 1988). Item-specific information consists of features unique to particular items, and is thought to be preferentially encoded for difficult-to-process items (for a review see McDaniel & Bugg, 2008). Relational information describes features that are shared across multiple items, such as semantic relatedness or serial order. Critically, recognition and recall are thought to differ in their reliance on item-specific and relational information at retrieval. Recognition relies on the discrimination of particular studied items from other items, so the retrieval of item-specific information is thought to primarily support performance in this task. Recall, in contrast, requires both discrimination and the generation of studied items from memory, which is thought to benefit from both item-specific and relational information.

Taken together, a robust incongruency benefit in recognition can be accounted for if incongruent items—like other difficult-to-process items documented in the literature—benefitted from enhanced item-specific encoding. Because recognition relies preferentially on the retrieval of item-specific information, enhanced item-specific encoding for incongruent items would explain why the congruency effect occurs. The task demands of free recall, on the other hand, allowed for both item and relational information to contribute to performance. If participants put more initial emphasis on processing incongruent items, enhanced item-specific encoding for these items may account for the incongruency benefit we observed reliably in the first study-test block. In subsequent blocks, however, participants may have learned to encode the congruent/single word items more effectively. The fact that this improvement is selective to free recall suggests that the underlying representations were more relational in nature. In line with this view, McDaniel and Bugg (2008) demonstrated that although difficult-to-process items benefit from enhanced item encoding, their easy-to-process counterparts are primarily encoded via relational processing that can be disrupted if the two trial types are intermixed in the same list.

Another layer to the item-relational framework is that the relative encoding of item-specific and relational information depends on list context, specifically whether the contrasting trial types are presented in mixed or pure lists (McDaniel & Bugg, 2008). In their review, better recognition for difficult items was reliably observed in both mixed and pure list conditions across multiple memory effects. However, better recall for difficult items was observed in mixed lists but not in pure lists. Chapter 2 (Davis et al., 2020) reported better recognition for incongruent than congruent selective attention items in both mixed and blocked lists (a within-subject variant of a pure list manipulation). Chapter 4 found superior recall for incongruent items under mixed list conditions, albeit isolated to the first of four study-test blocks.

A pilot study run in our lab may speak to the fourth quadrant of this test (recognition/recall) by list context (mixed/pure) matrix, namely whether an incongruency benefit in recall would be observed under blocked list conditions. A brief explanation of this pilot study and a figure of the results are presented in Appendix A. In short, unlike the experiments reported in Chapter 4, there was no hint of an incongruency benefit in the first (or any other) block. Although this fourth quadrant requires further study, these data offer a partial answer. The lack of an incongruency benefit in block 1 under blocked list conditions is in line with the predictions outlined by McDaniel and Bugg (2008).

As discussed earlier, the congruency effect may share certain properties with other difficulty effects in the memory literature. As reviewed in Chapter 1, effects such as the perceptual interference effect (Mulligan, 1999) and the orthographic distinctiveness effect (Hunt & Elliot, 1980; McDaniel et al., 2011; 2015) have been conceptualized using the item-relational framework. These manipulations that make stimulus processing difficult are thought to promote the encoding of item-specific information, which leads to better memory performance particularly in recognition tasks. Selective attention demands in our task may fit in this broad family of manipulations.

Defining "Difficulty"

This thesis began with a review of perceptual identification difficulty effects on long-term retention. In that chapter, a key issue was how to conceptualize the critical precursors that give rise to differential memory effects. We settled on the initial term "difficulty", borrowed from the desirable difficulty literature, to describe these precursors. This term acted as a placeholder to be further specified in order to reduce its cyclicality: "this difficulty manipulation is desirable for memory because it is difficult." One of the motivations for the review, and for the empirical work in this thesis, was to qualify what is meant by difficulty that is desirable.

An answer to this question, supported by work in this thesis, is that difficulty involves a set of conditions that promotes additional processing of higher-order representations of task relevant information. To break this down, higher-order representations broadly describe information beyond the low-level percept. For selective attention tasks that use verbal stimuli, Chapter 3 pointed to semantic interference as being an important factor. Examples from other areas include the compensatory processing account for the perceptual interference effect (Hirshman et al., 1994) pointing to lexical and semantic features of word stimuli, and the stage-specific control account for desirable difficulty effects (Ptok et al., 2019) pointing to the semantic categorization stage (as opposed to the response selection stage).

Task-relevant information describes the information available at encoding that is retrieved in the subsequent memory task. For the congruency effect, this would be semantic representations of target words. Recall that incongruent stimuli with pseudoword distractors still exhibited significant perceptual interference, as indexed by the naming time results. However, when semantic interference was minimized by presenting pseudowords as distractors, additional processing of meaning may not have occurred for targets. In conceptual memory tasks such as recognition, the group presented with pseudowords as incongruent distractors did not exhibit better memory for incongruent targets because additional semantic processing—critical for the subsequent memory benefit—was only done by the group presented with real words as incongruent distractors.

In a similar vein, Ptok et al. (2019) reported no benefit for incongruent targets in the response-conflict variant of their semantic categorization task. Presumably, this was the case because the congruency manipulation affected processing at the level of response rather than at the level of meaning. In this case, enhanced encoding of response representations would not have led to better memory performance because those representations were not the focus of retrieval in the old/new recognition task for target names.

The importance of retrieval demands in understanding the processes that underlie these memory effects is in line with the transfer appropriate processing principle (Morris, Bransford, & Franks, 1977). This principle highlights the relevance of processes engaged jointly at study and at test, despite the theoretical focus in the difficulty literature typically having been on activity at encoding. The comparison of recognition and free recall in Chapter 4 was one way of exploring this idea empirically. Even within a recognition task as well, we can think about the way our manipulations interface with both encoding and retrieval task demands to better understand how perceptual difficulties influence encoding. Difficulty effects may rely on a match—or successful transfer—between the representations that benefit from additional processing due to a difficulty manipulation and those that form the basis of task-relevant retrieval later.

As discussed in Chapter 1, this approach to conceptualizing memory effects helps us understand why certain difficulty manipulations do not lead to memory enhancements.

A prime example is the change detection study by Ortiz-Tudela et al. (2017). Recognition was worse for target objects that were incongruent to the surrounding scene compared to those that were congruent. On the surface, this result runs counter to the logic that semantic incongruency promotes additional processing of the target. However, this logic only applies if we consider semantic congruency as influencing memory via a mismatch between target and distractor information. In a change detection task, the more difficult condition may in fact be the congruent condition, because the to-be-identified target does not "pop out" as strongly as the incongruent targets do. Because visual search in this case is more difficult for congruent targets, these objects may have benefitted from additional semantic processing relative to their incongruent counterparts. In sum, semantic congruency may indeed affect encoding in a change detection paradigm, but understanding the manner in which it does requires us to think carefully about the encoding demands of the task.

Putting Desirable Difficulties in Context

Desirable difficulty effects have received a lot of attention in recent years in both fundamental and applied cognitive domains (e.g., Kühl & Eitel, 2016; Yue et al., 2013; Diemand-Yauman et al., 2011). It is tempting to think of them as a special category of phenomena that reveals how our cognitive systems can be jolted into encoding information better if learning is made hard enough. One conclusion this thesis can offer is that this is not necessarily the case.

A processing-oriented approach to understanding cognitive phenomena suggests that the memory effects we read about and report are merely the output of a whole host of processes that preceded the participant making a test response. It is critical to explore what these processes are, the environmental/experimental factors that activate them, and the resultant cognitive representations that become the basis for retrieval. Empirical work that takes this approach suggests that difficulty manipulations do not obligatorily produce desirable difficulty effects.

Taking these ideas outside of the lab, consider that we are predisposed to attend to, and to preferentially process, features that elicit a prediction error relative to our prior experience. As covered in Chapter 1, this idea is discussed both in the attention and performance literature (cognitive control; Shenhav et al., 2008) and in the memory literature (event segmentation; Kurby & Zacks, 2008). This response optimization may involve adjustments in control processes that influence the cognitive representations of situation-relevant features. Enhanced retrievability of stimuli that elicit prediction error may thus be a by-product of an interaction between control operations and cognitive representations. Our ability to observe these by-products and call them “difficulty effects” depends on various factors, including the representations influenced by processing adjustments and their compatibility with the retrieval demands of the memory task.

Integrating Attention, Learning, and Memory

Attention and Memory

In cognitive psychology, it is important to remember that attention and memory are inherently interdependent. What is attended to—and how it is attended to—depends on prior experience, which in turn affects how well it is later retrieved from memory. This interdependence points to cognitive representations as being key to many of the effects we observe. Cognitive representations based on prior experience can be an object of our remembering, but they can also produce top-down influences on perception and attention. Therefore, the study of attention effects on memory ought to examine carefully the potential mediating role of cognitive representations in such effects. This logic was central to Chapter 3—we examined how perceptual and semantic interference at encoding interface with the conceptual representations of the words presented. If we had ignored the potential role of the pre-existing knowledge of word meaning, these experiments would not have been conducted.

It is important to point out, however, that a focus on these representations per se may not be sufficient to explain all effects of attention on memory. Whittlesea's SCAPE model of episodic memory highlights the memory system's preservation of processing operations rather than stable representations (Whittlesea, 1997). This account suggests that the stimulus complex at any given point in time consists of the current stimulus, task, and context. The complex acts as a cue to prior memory representations, which then influence processing during the current encoding opportunity. This experience is then stored as a new episode to be retrieved in subsequent encoding opportunities. Thus, this model suggests that performance in various cognitive tasks is supported by the "interactive control" of the stimulus compound and the bank of prior experiences. The SCAPE account emphasizes not only these extant representations, but also the cognitive operations that act on and are influenced by them. In a similar vein, the approach taken in this thesis involved the conceptualization of the potential processes engaged by the stimuli and tasks at encoding and at retrieval.

Encoding versus Retrieval Effects

Another qualification worth noting is the distinction between an encoding effect and a retrieval effect. Encoding effects are how desirable difficulty effects have been described: The difficult trial type is encoded better due to additional processing at study, and this difference is expressed in a subsequent memory task. A retrieval effect, in contrast, does not require differential encoding across trial types at the time of study. Instead, better memory performance for the difficult trial type results from enhanced retrievability of unusual features at the time of test, wherein “difficulty” constitutes a cue to better retrieve those items from memory relative to easy trials.

In Chapters 2 and 4, the recognition task re-presented incongruent distractors at test. This potentially enhanced the retrievability of incongruent targets, driven by study context reinstatement. The congruency effect observed using this design has been driven by higher hit rates, lower false alarm rates, or both, for incongruent trials relative to congruent trials (Rosner et al., 2015, Davis et al., 2020). In the experiments presented in Chapters 2 and 4, the effect was at times driven only by the false alarms (e.g., Experiment 2 in Chapter 2, Davis et al., 2020), which may be interpreted as congruency influencing retrieval more so than it does encoding. A dual-process account in favour of the congruency effect being an encoding effect has been proposed (see Davis et al., 2020), and the effect has been observed when distractors were not reinstated at test (Experiment 2, Rosner et al., 2015; Chapter 3, Davis & Milliken, in prep).

Two other observations may further address this issue. First, Chapter 2 reported a congruency effect in both mixed and blocked lists (Exp 2B; Davis et al., 2020). In the mixed list, the "incongruent" cue would have been useful when retrieving targets from memory, because these items were encoded in the context of easier congruent items. In the blocked list, however, the "incongruent" cue would not have been helpful, for all the trials in the preceding study list were incongruent. Therefore, discriminating between old incongruent targets and new incongruent targets would not have benefitted from this retrieval strategy. The magnitude of the congruency effect was no different between these two list conditions, suggesting that a retrieval account is not sufficient.

Second, Chapter 4 reported a congruency effect in free recall that was isolated to the first of four study-test blocks. Critically, this was driven primarily by an improvement in subsequent blocks for the easier trial type (congruent/single word), while recall for incongruent targets remained relatively stable. A retrieval explanation for this pattern is unlikely, for the use of an "incongruent" retrieval cue would not predict a select improvement for the easier trials nor the corresponding elimination of the congruency effect. Any changes to this retrieval strategy across blocks would likely have been observed as changes in incongruent target performance.

Thus, processing adaptations at encoding may better account for the pattern in free recall across blocks, and perhaps, by extension the effect in recognition. Nonetheless, this distinction between encoding and retrieval effects—and whether they can be fully distinguished from each other at all—is a rich theoretical issue that ought to be discussed more in the desirable difficulty literature.

Concluding Remarks

Attention and memory are heavily interdependent. The goal of this research program on selective attention effects on memory was to study this interdependence. The exploration of mental processes is necessarily an indirect endeavour, and the empirical work presented here aimed to triangulate various approaches to make inferences about the processes that underlie this particular perceptual difficulty effect. These approaches were drawn from both the attention and memory domains, to place this effect in the context of other potentially related literatures while accounting for both "ends" of the cognitive pipeline—encoding and retrieval.

The importance of accounting for both encoding and retrieval processes cannot be stressed enough. While doing so may lead us to stray from a single procedure, it gives us an opportunity to work through the inevitable nuances that come with studying transient processes and their less-transient consequences. This in turn allows us to get a fuller picture of the attention-memory interdependence, which is presumably shared across many effects in the literature. Finding similarities across stimuli, patterns of results, and frameworks helps focus the work on the cognitive processes themselves, rather than on the task(s) used to measure them. The work presented here has improved our understanding of a particular perceptual difficulty effect on subsequent memory, but has also helped to elucidate the broader issue of why a wide range of perceptual difficulty manipulations produce similar effects.

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Appendix A:

Pilot Experiment: Congruency with a Blocked-List Design in Free Recall

To examine the effect of encoding list context on the congruency effect in free recall, a pilot experiment was run that presented congruent and incongruent trials in separate lists (n=24). The procedure and design were the same as for the control group in Experiment 1B in Chapter 4, except that participants were presented with one trial type (congruent or incongruent) in the first two study phase blocks and the other trial type in the latter two study phase blocks. Which trial type was presented first was counterbalanced across participants.

Mean proportions of correctly recalled trials are displayed in Figure A1. It is important to note that adjacent bars for congruent and incongruent trials within a study-test block are from separate groups of participants due to the blocked list manipulation. The most notable observation from this pilot experiment is that, in contrast to Experiments 1B and 2 (recall group) in Chapter 4, there was no hint of an incongruency benefit in the first block. In fact, the opposite numerical pattern was observed–better recall for congruent than incongruent items.

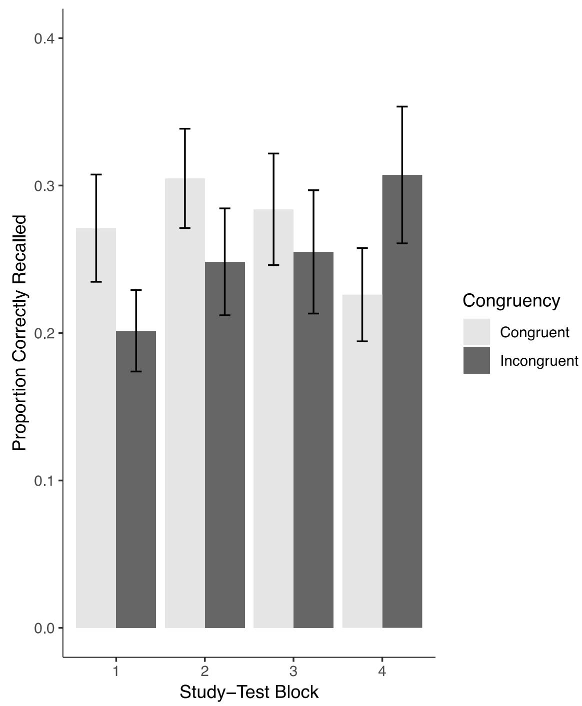

Figure A1: Mean proportion recalled in a pilot study that presented congruent and incongruent trials in separate list contexts ('blocked' manipulation). Error bars depict the SEM.