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Integrative Priming Occurs Rapidly and Uncontrollably During Lexical Processing

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Lexical priming, whereby a prime word facilitates recognition of a related target word (e.g., *nurse* → *doctor*), is typically attributed to association strength, semantic similarity, or compound familiarity. Here, the authors demonstrate a novel type of lexical priming that occurs among unassociated, dissimilar, and unfamiliar concepts (e.g., *horse* → *doctor*). Specifically, integrative priming occurs when a prime word can be easily integrated with a target word to create a unitary representation. Across several manipulations of timing (stimulus onset asynchrony) and list context (relatedness proportion), lexical decisions for the target word were facilitated when it could be integrated with the prime word. Moreover, integrative priming was dissociated from both associative priming and semantic priming but was comparable in terms of both prevalence (across participants) and magnitude (within participants). This observation of integrative priming challenges present models of lexical priming, such as spreading activation, distributed representation, expectancy, episodic retrieval, and compound cue models. The authors suggest that integrative priming may be explained by a role activation model of relational integration.

Keywords: associative priming, integrative priming, relational integration, semantic priming, word recognition

One of the most robust phenomena of psychology is the lexical priming effect, whereby responding to a target word is facilitated by the prior presentation of a related prime word (for an extensive review, see Hutchison, 2003; Lucas, 2000; McNamara, 2005; Neely, 1991). In a seminal experiment, Meyer and Schvaneveldt (1971) simultaneously presented two letter strings in a lexical decision task (LDT; i.e., word/nonword judgments). They found that related words (e.g., *bread-butter*) elicited faster lexical decisions than unrelated words (e.g., *nurse-butter*). Since that classic demonstration (see also Meyer, Schvaneveldt, & Ruddy, 1975; Tweedy, Lapinski, & Schvaneveldt, 1977), researchers have distinguished two broad classes of relation between primes and targets. *Association* refers to a relation in language use, typically defined as the proportion of participants who produce a given target word (e.g., *pepper*) in response to a cue word (e.g., *salt*) in the free-association task. *Similarity* refers to a relation in word meaning, typically defined as the degree of feature overlap between the concepts (e.g., *dog-wolf*). Thus, one may distinguish *associative priming*, which is based on association strength, from *semantic priming*, which is based on featural similarity (see, e.g., Fischler, 1977; Hutchison, 2003; Lucas, 2000; McNamara, 2005; McRae & Boisvert, 1998; Moss, Ostrin, Tyler, & Marslen-Wilson, 1995; Shelton & Martin, 1992; Thompson-Schill, Kurtz, & Gabrieli, 1998). The purpose of the present study was to demonstrate and characterize another source of lexical priming that is independent of both associations and similarity. Namely, we examined the influence of relational integration on lexical processing.

Relational Integration

By *relational integration*, we mean a process in which individual noun concepts are combined to create a unitary representation. More formally, the first noun (i.e., the *modifier*) designates a subclass of the second (i.e., the *head*), such that they jointly refer to a single entity (or class). There are various relations that may be inferred to integrate a pair of concepts. For instance, the concepts *table* and *vase* may be integrated via a *location* relation, as in a vase *located on* a table. Concepts may also be integrated by relations of *causation* (e.g., *rope burn*), *composition* (e.g., *copper pot*), *time* (e.g., *winter holiday*), *function* (e.g., *sketch pen*), *partonomy* (e.g., *bear paw*), *topic* (e.g., *cowboy film*), *production* (e.g., *wind power*), and so forth.[1] Such relational integration is ubiquitous among noun compounds. Gagné (2000) found that approximately 81% of the noun compounds in the Brown corpus (Kučera

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[1] The number and specificity of such integrative relations have been the subject of much debate. Many researchers have explicitly claimed or tacitly assumed that a small set of general relations (e.g., *have*, *make*, and the like) is sufficient to characterize all or most instances of relational integration (Coolen et al., 1991; Gagné, 2000; Lees, 1963; Levi, 1978; Ryder, 1994; Warren, 1978). However, these general relations have been criticized for being too vague to describe their actual cognitive instantiations adequately (H. H. Clark, 1983; Devereux & Costello, 2005; Downing, 1977; Estes, 2003b; Estes & Jones, 2006; Kay & Zimmer, 1976; Maguire et al., 2007; Murphy, 1988, 2002; Murphy & Wisniewski, 2006). For example, although Levi classified both *nut bread* and *fruit tree* as exemplars of a general *have* relation (i.e., Y *has* X), the former instantiates more specifically a *containment* relation (i.e., bread that *contains* nuts), whereas the latter instantiates a seemingly different *production* relation (i.e., tree that *produces* fruit). Although the evidence favors more specific integrative relations, their specificity makes no difference to the present investigation.

& Francis, 1967) and 86% in Warren's (1978) sample are understood via relational integration. More concretely, the opening sentence of this article contains three unique noun compounds, all of which are understood by relational integration (e.g., *priming effect, target word, prime word*).

Noun compounds serve an important linguistic function: They refer concisely. That is, lengthy references can be reduced by replacing the modifying phrase with a single modifier noun. To illustrate, the noun compound *animal hospital* is much more concise than its explicit phrasal reference, "hospital for treating animals." Similarly, a vase located on a table can be denoted by the shorter name *table vase*, and a holiday during the winter can be abbreviated as *winter holiday*. Noun compounds are particularly useful when one instance of the head noun category must be distinguished from another. For example, an animal hospital is a specific type of hospital, namely, one that treats animals. The modifier specifies how the compound concept differs from other members of the head category (see, e.g., E. V. Clark & Berman, 1987; Gagné & Murphy, 1996; Glucksberg & Estes, 2000; Springer & Murphy, 1992; Swinney, Love, Walenski, & Smith, 2007). For instance, roller skates have wheels, whereas ice skates have blades, and a rope burn is caused by friction, whereas most burns are caused by direct heat.

Subclassification differentiates integrative relations from other lexical relations known to elicit priming. Henceforth, word pairs separated by an arrow will denote a lexical decision trial (e.g., *prime* → *target*). Although synonymy (e.g., *baby* → *infant*) and antonymy (e.g., *order* → *chaos*) both elicit priming (Hodgson, 1991; McKoon & Ratcliff, 1995; Perea & Rosa, 2002), they do not entail subclassification. Nor do associative relations (e.g., *salt* → *pepper*) or category coordinates (e.g., *dog* → *wolf*) involve subclassification. *Salt pepper* is not a type of *pepper,* nor is *dog wolf* a type of *wolf*. Opaque compounds (e.g., *honeymoon*; de Mornay Davies, 1998; Jarema, Busson, Nikolova, Tsapkini, & Libben, 1999; Libben, Gibson, Yoon, & Sandra, 2003; Seidenberg, Waters, Sanders, & Langer, 1984) do have a unitary representation, but they do not entail subclassification; a *honeymoon* is not a subclass of moons. Finally, we should reiterate that we are concerned here only with simple noun–noun compounds. Thus, we do not consider instances in which a target noun is integrated with an adjective (e.g., *red* → *apple*; Smith, Osherson, Rips, & Keane, 1988) or with a more elaborate context, such as a sentence frame, a text passage, or general world knowledge (Forster, 1981; Garrod & Terras, 2000; Hagoort, Hald, Bastiaansen, & Petersson, 2004; Hess, Foss, & Carroll, 1995).

The experiments reported below demonstrate that relational integration occurs routinely during lexical processing and that its effect is to facilitate word recognition (henceforth *integrative priming*). In order to determine whether this integrative priming can be explained by any present model of lexical priming, we now review those extant models.

Models of Priming

Various mechanisms have been proposed to explain lexical priming. These mechanisms vary in terms of the theoretical construct assumed to explain priming: Some models explain lexical priming as a consequence of association strength, others appeal to featural similarity, and still others attribute priming to familiarity. Below we describe several influential models of lexical priming, with particular emphasis on their explanatory constructs. To be clear, we do not intend to present a thorough review of the literature here; excellent reviews are available elsewhere (e.g., Hutchison, 2003; Lucas, 2000; McNamara, 2005; Neely, 1991). Rather, our intention is to provide a general and brief overview of the extant models of lexical priming so that we may assess whether any of them can explain the presumed integrative priming effect.

Spreading Activation

The spreading activation model (Anderson, 1983; Collins & Loftus, 1975; McNamara, 1992a, 1992b, 1994) assumes a localist semantic network in which individual concepts are represented as holistic nodes connected via descriptive links. When a word is heard or read, its node becomes activated, and this activation subsequently spreads to other nodes with which it is associated. By this model, priming occurs when the prime word preactivates an associated target word. The model thus ascribes priming to association.

Distributed Representation

The distributed representation model assumes a semantic network consisting of feature nodes that are distributed across the brain, and it represents concepts as dynamic spatio-temporal patterns of activation (e.g., Becker, Moscovitch, Behrmann, & Joordens, 1997; Masson, 1995; McRae, de Sa, & Seidenberg, 1997; Plaut & Booth, 2000). For example, the word *dog* does not activate a single node in the network (as assumed by localist models), but rather activates a set of feature nodes (e.g., four-legged, hairy, barks) that are distributed across brain regions. Priming occurs when the prime and target concepts exhibit overlapping patterns of activation. Thus, the distributed representation model ascribes priming to featural similarity. The more features two concepts have in common, the greater the overlap in neural activation, and hence the greater the lexical priming. A notable exception is the model of Plaut and Booth (2000), who posited an additional word-level representation that may induce priming by association.

Expectancy

According to the expectancy model (Becker, 1980; de Groot, 1984; Fischler & Bloom, 1979; Neely, 1977; Posner & Snyder, 1975), the prime word may induce generation of a set of expected target words. For example, *cat* may elicit generation of *dog*, *mouse*, and *kitten* as likely targets. Priming occurs when an expected word appears as a target. The expectancy model therefore ascribes priming to association.

Semantic Matching

Semantic matching (i.e., coherence checking) refers to a search for a meaningful relation between prime and target (de Groot, 1984; Forster, 1981; Neely, 1977; Neely, Keefe, & Ross, 1989; Seidenberg et al., 1984). In an LDT, for instance, the presence of a relation between prime and target indicates that the target must be a word because nonwords are generally unrelated to words. Some investigations of semantic matching have used primes and targets with taxonomic relations (e.g., *bird* → *robin*; Neely, 1977; Neely et al., 1989), whereas others have used associative relations (e.g., *stork* → *baby*; Anaki & Henik, 2003; Chwilla, Hagoort, & Brown, 1998; de Groot, 1984, 1985; Hutchison, 2002). Thus, priming via semantic matching may be attributed to either similarity or association.

Episodic Retrieval

The general premise of an episodic retrieval model is that the target word induces retrieval of the prime word, which may affect responding to that target (Bodner & Masson, 2001, 2003; Whittlesea & Jacoby, 1990). Like investigations of semantic matching, episodic retrieval studies tend not to distinguish between associative and semantic relations. Thus, the episodic retrieval model ascribes priming to either similarity or association.

Compound Cue

Ratcliff and McKoon (1988) posited that the prime and target concepts "join together to form a compound cue" (p. 385), which is then matched against items in long-term memory. Consequently, the "response to the target will be facilitated to the extent that the prime and target are associated in memory" (p. 386; see also Dosher & Rosedale, 1989; McKoon & Ratcliff, 1992). Although McKoon and Ratcliff attributed priming to association, they conceptualized the association between prime and target as the familiarity of the compound. The compound cue model therefore attributes lexical priming to familiarity.

Integrative Priming

As described above, the extant models all ascribe lexical priming to associative strength, semantic similarity, or compound familiarity. And indeed, many experiments have demonstrated effects of these three factors on lexical processing. The goal of the present experiments was to investigate whether relational integration also affects lexical processing. Some prior evidence suggests that it might. As Seidenberg and colleagues (1984) noted, "It may be difficult to inhibit recognizing at least some relations between [target] word and [prime] context, because identifying them is a normal and overlearned part of the comprehension process" (p. 324). Given their ubiquity (Gagné, 2000), integrative relations may well be overlearned and difficult to ignore. Indeed, thematic relations affect some basic cognitive processes from which they are theoretically independent, such as similarity (Bassok & Medin, 1997; Estes, 2003a; Simmons & Estes, 2008; Wisniewski & Bassok, 1999) and categorization (Lin & Murphy, 2001; Murphy, 2001). It therefore seems likely that relational integration would affect lexical processing as well.

Moreover, integrative relations could plausibly influence word recognition via basic cognitive mechanisms. For instance, rather than checking whether the target is associatively or semantically related to the prime (see the *Semantic Matching* section), participants might check whether the target can be integrated easily with the prime. Such a retrospective integration check could clearly affect lexical decisions: If prime and target can be integrated, then the target must be a word because a prime cannot be integrated with a nonword. Alternatively, relational integration could affect lexical decisions prospectively. Noun concepts are associated with the particular integrative relations that they most frequently instantiate (Gagné & Shoben, 1997; Storms & Wisniewski, 2005). For instance, *chocolate* frequently instantiates the *composition* relation (e.g., chocolate bar, chocolate bunny, chocolate coin, and the like). During lexical processing, then, a prime word (e.g., *chocolate*) could activate the integrative relation that it most frequently instantiates (i.e., *composition*), and that integrative relation could activate other concepts that may plausibly instantiate it. These and other possible mechanisms of integrative priming are considered in greater detail in the General Discussion section.

To provide the clearest possible contrast with the extant models, we tested whether integrative priming would occur between concepts that are dissimilar and unassociated and that are unfamiliar as a phrase. Regarding similarity, relational integration is actually more frequent among dissimilar concepts than among similar concepts (Wilkenfeld & Ward, 2000; Wisniewski, 1996). Because relational integration requires that the two concepts perform complementary roles in a thematic relation (see M. Jones & Love, 2007; Wisniewski, 1997; Wisniewski & Bassok, 1999), integrative compounds tend to consist of semantically dissimilar concepts (Estes, 2003a; Wisniewski & Love, 1998). For example, the *containment* relation (e.g., *box wine*) entails complementary roles of *container* and *contained*. Typically, the different roles of a relation are performed by concepts with different features. A liquid, for instance, is more suitable for the *contained* role than for the *container* role. Consequently, relational integration is rare among similar concepts.

In contrast, relational integration appears to be relatively common among associated, familiar compounds. Most phrasal associates (e.g., *spider web*; Hodgson, 1991; Hutchison, 2003; Williams, 1996) are understood via relational integration, and moreover, familiar noun compounds are understood more quickly than novel compounds (Wisniewski & Murphy, 2005). These findings suggest that integrative priming may occur often among associated, familiar concepts. In such cases, however, it is impossible to determine whether facilitation of the target word is due to relational integration, association strength, or compound familiarity. If relational integration facilitates lexical processing, then concepts that are dissimilar, unassociated, and unfamiliar (e.g., *donkey parade*) should also exhibit lexical priming. Such a result would not be explicable via any of the extant models of lexical priming.

Coolen, van Jaarsveld, and Schreuder (1991) provided preliminary evidence that relational integration affects lexical processing. In one experiment, they preceded target words with a prime word that produced either a highly integrative or a less integrative compound. For instance, the target word *market* followed either *lemon* or *beard*, the former noun compound (*lemon market*) being more easily integrated than the latter (*beard market*). Coolen et al. found a small (16-ms) but significant integration effect, with target words eliciting faster responses after a highly integrative prime than after a less integrative prime. In another experiment, Coolen and colleagues presented both lexicalized compounds (e.g., *cheesecake*) and novel compounds (e.g., *slumbuilding*), and the participants' task was to indicate whether the given compound was lexicalized (i.e., an existing compound) or novel. In fact, they presented two types of novel compounds—some were highly interpretable (e.g., *slumbuilding*), whereas others were less interpretable (e.g., *parakeetfiber*). They found that rejection of the highly interpretable novel compounds was slower and less accurate than rejection of the low-interpretability compounds. Successful integration of a novel compound interfered with the "nonlexicalized" response. Coolen and colleagues thus demonstrated not only that relational integration affects lexical processing but also that it may occur in tasks for which it actually hinders performance. These findings therefore suggest that relational integration is an uncontrolled component of lexical processing.

However, the study by Coolen et al. (1991) suffers from two important limitations. First, although Coolen et al. showed a relative difference in response times for highly integrative and less integrative word pairs, their demonstration did not distinguish between facilitation of the highly integrative pairs and interference of the less integrative pairs. Only if a target elicits faster responses after an integrative prime than after a neutral prime can facilitation be concluded. Second and perhaps more critically, their results are also equivocated by potential confounding factors. Although associative relatedness was matched across the highly integrative and less integrative pairs, similarity and familiarity were not. Thus, these results are more tentatively suggestive than definitively indicative of integrative priming.

Overview of Experiments

The present experiments were undertaken with two primary goals in view: Our empirical goal was to document integrative priming and to describe its properties, and our theoretical goal was to test whether any extant model can account for integrative priming. In each of the experiments, we either controlled or manipulated the associative strength, semantic similarity, and compound familiarity of the prime and target concepts. To facilitate comparison with prior studies, we also manipulated two key factors that are often used in investigations of lexical priming. First, in Experiments 1 and 2, we compared integrative priming with associative priming and semantic priming, respectively, across manipulations of *stimulus onset asynchrony* (SOA), which is the delay between onset of the prime and onset of the target. This factor is typically manipulated in order to investigate the time course of a priming mechanism. For instance, both associative priming and semantic priming are observed at short (i.e., < 300 ms) and intermediate SOAs (approximately 300 ms–800 ms), but associative priming continues to increase in magnitude across longer SOAs (i.e., $\geq 1{,}000$ ms), whereas semantic priming tends to dissipate at those later SOAs (e.g., den Heyer, Briand, & Smith, 1985; Hutchison, Balota, Cortese, & Watson, 2008; Neely, 1977; Perea & Rosa, 2002).

Second, in Experiments 3 and 4, we manipulated the *relatedness proportion* (RP), which is the proportion of trials in which the prime and target words are related. This is a key factor for determining whether the priming mechanism is under strategic control by participants. If a mechanism is "controlled," then its effect should be accentuated when that mechanism is effective for task performance, and should be attenuated when the mechanism would be ineffective. To illustrate, suppose that primes and targets are easily integrated on 80% of the trials. In this case, relational integration would likely facilitate verification of the targets, and hence the integrative priming effect should be large. But if only 20% of trials were easily integrated, then relational integration would not be effective, and thus the effect should be diminished or altogether absent. So the occurrence of an RP effect is commonly held to indicate controlled processing, and conversely if an effect is impervious to RP manipulations, then the mechanism is said to be "uncontrolled" (for a review, see Hutchison, 2007, Table 1).[2]

Because relational integration is so extensively practiced (Gagné, 2000), we hypothesized that it is an automated component of lexical processing. More specifically, we predicted that integrative priming would occur rapidly (i.e., at brief SOAs) and uncontrollably (i.e., regardless of RP). Together these experiments will delineate the basic properties of integrative priming.

Experiment 1

In Experiment 1, we sought the first unequivocal evidence of integrative priming. We therefore compared response times for the same target word following either an integrative prime or a neutral baseline prime. The integrative primes were constrained to be dissimilar to and unassociated with their targets so that any observed difference between the baseline and integrative conditions would not be attributable to semantic or associative priming. For comparison to a well-established lexical priming effect, we also included associative primes. Thus, the same target word (e.g., *wine*) followed either a baseline prime (i.e., ********), an associative prime (e.g., *cork*), or an integrative prime (e.g., *box*). The targets were more strongly associated with their associative primes than with their integrative primes and were more easily integrated into a sensible phrase with their integrative primes than with their associative primes.

Associative priming generally increases from brief to long SOAs (see Hutchison, 2003, Table 3; see also Hutchison et al., 2008). To compare this pattern of associative priming with the presumed integrative priming, we used an intermediate SOA of 500 ms and a late SOA of 2,000 ms. This intermediate SOA is comparable to the 540-ms SOA used by Coolen and colleagues (1991) in their study of relational integration, and this late SOA is known to produce associative priming (den Heyer et al., 1985; Neely, 1991; Perea & Rosa, 2002). The experiment therefore had a 3 (prime: baseline, associative, integrative; within participants) $\times$ 2 (SOA: 500, 2,000 ms; between participants) mixed design using a standard LDT.

Method

Participants. All participants in each of the experiments reported herein were undergraduates at the University of Georgia (except where otherwise noted), all received partial course credit for participation, and all spoke English as their native language. None participated in more than one of the experiments or rating tasks reported below. In Experiment 1, 62 participants were randomly assigned to the 500-ms ($n = 31$) or the 2,000-ms ($n = 31$) SOA condition, and an additional 72 participants provided similarity ratings and integration ratings.

Stimuli. Stimuli were selected on the basis of associative strength, semantic similarity, and integratability. In anticipation of the subsequent experiments, 50 targets (e.g., *book*) were each

[2] Historically, many researchers have used the terms *strategic* and *automatic* instead of *controlled* and *uncontrolled*, respectively. However, *automatic* has been used to refer to any or all of several properties (e.g., uncontrolled, unintentional, fast, effortless, efficient), and hence its use conflates properties that in principle are independent (see Moors & De Houwer, 2006). To circumvent this conflation, we heed Moors and De Houwer's (2006) suggestion to refer more precisely to the specific property under investigation.

paired with an integrative prime (e.g., *travel*), an associative prime (e.g., *author*), and a semantic prime (e.g., *article*). Association values were obtained from the University of South Florida free-association norms (Nelson, McEvoy, & Schreiber, 2004). For each of the 150 prime–target pairs, both the forward (e.g., prime → target) and backward (e.g., target → prime) association probabilities were obtained.

Additionally, 24 participants rated the semantic similarity of all 150 prime–target pairs on a scale ranging from 1 (*not at all similar*) to 7 (*very similar*). Because integration is known to affect perceived similarity (Bassok & Medin, 1997; Estes, 2003a; M. Jones & Love, 2007; Simmons & Estes, 2008; Wisniewski & Bassok, 1999), it was important to emphasize to participants that they should rate *featural* similarity (McRae & Boisvert, 1998). Thus, the instructions stated the following:

> For example, DOTS and STRIPES are similar (both are types of patterns or designs). However, SHIRT and STRIPES would not be similar. Even though stripes are often found on shirts, a shirt is a type of CLOTHING. Furthermore, whereas ZEBRA is associated with STRIPES, these two words are also not very similar, because they belong to different categories (i.e., animal and pattern categories).

Finally, integratability was assessed via a procedure adapted from Solomon and Pearlmutter (2004). An independent group of 27 participants rated the extent to which each of the 150 prime–target pairs, presented individually in isolation, could be linked together to produce a sensible phrase. The scale ranged from 1 (*not linked*) to 7 (*tightly linked*). Similarity and integration were again distinguished in the instructions:

> For example, although KETCHUP and MUSTARD are similar in meaning and are often associated with each other, these words cannot be linked to form a sensible phrase. On the other hand, SILVER BRACELET could be linked together as a BRACELET made of SILVER.

Experimental stimuli were selected on the basis of the association values and the integration ratings. Forty-five targets, each paired with an associative prime and an integrative prime, were selected for use in the present experiment. All experimental stimuli are listed in Appendix A, and stimulus characteristics are summarized in Table 1. As evident in the table, the associated primes were more strongly associated with the targets, whereas the integrative primes were more easily integrated with the targets.

Because interpreting novel compounds in isolation may be somewhat unnatural, a contextualized measure of integratability was also collected by presenting the prime–target pairs in a neutral sentential context. All context sentences consisted of a common name as the subject, followed by a generic verb, and the target noun compound as a direct object (e.g., "Betty asked about the *travel book*"). Twenty-one undergraduates at Francis Marion University judged "the sensibility of each word pair within its sentence" on a scale ranging from 1 (*not at all sensible*) to 7 (*completely sensible*). For each target (*book*), the same neutral sentence frame was used with each of the three prime types, though the sentences were presented in random order. Results were remarkably similar to the isolated integratability ratings reported in Table 1. The integrative prime–target pairs ($M = 5.32$, $SD = 1.09$) were judged more sensible than either the associative ($M = 3.87$, $SD = 1.03$) or the semantic ($M = 3.47$, $SD = 0.95$) pairs. Moreover, the isolated and contextualized integratability ratings were correlated strongly, $r(135) = +.83$, $p < .001$. Thus, the isolated and contextualized measures of integratability converged on the conclusion that the targets were more easily interpreted as a sensible phrase with their integrative primes than with their associative primes.

The associative primes were more similar to the targets than were the integrative primes (see Table 1). This is most likely attributable to the negative relationship between semantic similarity and relational integration that is regularly observed in research on conceptual combination (Estes, 2003a; Wilkenfeld & Ward, 2000; Wisniewski, 1996). The present stimulus set corroborates this general relationship: Across all stimulus pairs used in Experiments 1 and 2 (see Appendix A), similarity ratings and integratability ratings exhibited a significant and relatively strong negative correlation, $r(135) = -.60$, $p < .001$. This covariation of similarity and integratability is addressed in the *Results* section. The only other significant intercorrelation among the variables presented in Table 1 was a positive relation between forward and backward association values, $r(135) = +.30$, $p < .001$.

In addition to the 45 experimental targets, there were also 45 pronounceable nonword targets (e.g., skup, revicle). Thirty nonword targets were preceded by a word prime (as in the associative and integrative conditions), and 15 were preceded by a row of eight asterisks (as in the baseline condition).

Procedure. Participants were tested individually in a sound-attenuated room, and the experiment was administered via DirectRT experimental software (Version 2004) on Dell personal computers with 15-in. (38-cm) LCD displays and a 17-ms refresh rate. Prime type was manipulated within participants, such that each participant was presented with 15 experimental targets in each of

Table 1
Integration Ratings, Association Values, and Similarity Ratings of the Stimuli Used in Experiments 1 and 2

	Integration		Association: Forward		Association: Backward		Similarity	
Prime type	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Integrative	5.41	0.85	0.02	0.03	0.00	0.01	2.14	0.87
Associative	3.96	0.65	0.48	0.20	0.02	0.02	3.71	1.50
Semantic	3.00	0.74	0.02	0.02	0.01	0.02	4.68	0.77

the three prime conditions (baseline, associative, integrative). Experimental items were rotated across three lists, with each target appearing only once per list. Participants initiated each trial by pressing the space bar. After a 500-ms pause, a red fixation cross (+) appeared in the center of a black screen for 500 ms. The prime then appeared centrally for 100 ms, followed by a blank interval of either 400 ms or 1,900 ms, depending on the SOA condition (i.e., 500 ms, 2,000 ms). Finally, the target appeared centrally and remained on the screen until the participant indicated by key press whether the target was a word or a nonword. Primes were presented in red font in the center of a black screen, whereas targets appeared in white font. The relevant part of the instructions read as follows:

> a red word (or a row of asterisks ********) will appear . . . but you don't have to respond to it. Then, a white letter string will appear, and your task is to indicate whether it's a word (e.g., "giraffe") or not (e.g., "blump") . . . . The computer will be timing your responses, so please respond as quickly as you can, without making errors. And remember, you only have to respond to the second letter string (which will be in white), by pressing J for a word or F for a nonword.

The intertrial interval was 1 s. Ten practice trials preceded the 90 experimental trials.

Results and Discussion

Both associative (e.g., *cork*) and integrative (e.g., *box*) primes facilitated responding to target words (e.g., *wine*), but they exhibited differential patterns of priming: Whereas associative priming increased across SOAs, integrative priming decreased across SOAs. The observed integrative priming was not attributable to association, similarity, or familiarity, and hence this experiment provided the first unequivocal evidence that relational integration facilitates lexical processing. Priming effects (i.e., baseline RT – experimental RT) are illustrated in Figure 1, and full results are presented in Table 2.

In each of the experiments reported herein, response times from incorrect trials and response times more than two standard deviations above or below the condition mean (calculated individually for each participant) were excluded from all analyses. Across experiments, this resulted in the removal of 2%–5% of the data. In each experiment, we analyzed results separately across participants (F_p, t_p) and items (F_i, t_i). We analyzed data from the present experiment initially via a 3 (prime: baseline, associative, integrative) × 2 (SOA: 500 ms, 2,000 ms) mixed analysis of variance (ANOVA). Accuracy rates exhibited only a main effect of prime that was significant across participants, $F_p(2, 120) = 3.61$, $p < .05$, but not across items, $F_i(2, 88) = 1.13$, $p = .33$. Accuracy was not analyzed further.

The associative and integrative primes elicited faster responses than the baseline primes, as indicated by a significant main effect of prime, $F_p(2, 120) = 19.19$, $p < .001$; and, $F_i(2, 88) = 33.85$, $p < .001$. Lexical decisions were also faster at the 500-ms SOA than at the 2,000-ms SOA, $F_p(1, 60) = 5.29$, $p < .05$; and, $F_i(1, 44) = 199.71$, $p < .001$. Most important, associative priming and integrative priming exhibited different time courses; the Prime × SOA interaction was significant, $F_p(2, 120) = 3.04$, $p = .05$; and, $F_i(2, 88) = 4.17$, $p < .05$. To examine this interaction more closely, we conducted a further 2 (prime: associative, integrative) × 2 (SOA: 500 ms, 2,000 ms) mixed ANOVA on the priming effects illustrated in Figure 1. Whereas associative priming increased across SOAs, integrative priming decreased across SOAs. This interaction was significant, $F_p(1, 60) = 6.95$, $p = .01$; and, $F_i(1, 44) = 8.49$, $p < .01$.

Recall that the target concepts were more similar to the associative primes than to the integrative primes (see Table 1). To investigate whether this conflation may explain the differential time courses of the associative and integrative conditions observed here, we conducted a 2 (prime: associative, integrative) × 2 (SOA: 500 ms, 2,000 ms) analysis of covariance across items, with similarity ratings included as the covariate. The effect of similarity was nonsignificant, $F_i(1, 87) = 0.64$, $p = .43$, and the Prime × SOA interaction again was significant, $F_i(1, 87) = 4.90$, $p < .05$. Thus, similarity does not explain the divergent response patterns evident in Figure 1.

Finally, to examine whether the integrative priming observed here may be due to compound familiarity, we asked 29 undergraduates to rate the integrative prime–target pairs on a scale ranging from 1 (*unfamiliar*) to 7 (*very familiar*). Although the stimuli ranged in familiarity from 2.97 (*monkey foot*) to 6.76 (*race car*), these familiarity ratings did not correlate significantly with the magnitude of integrative priming (i.e., baseline RT – integrative RT) in either the 500-ms ($r = -.23$, $p = .13$) or the 2,000-ms SOA condition ($r = -.16$, $p = .28$). Thus, the integrative priming was not attributable to compound familiarity.

In summary, relational integration facilitated lexical processing. The finding that target words elicited faster lexical decisions after an integrative prime than after a neutral baseline prime provides the first demonstration that the effect of relational integration is facilitative. Moreover, because the integrative primes and targets were unassociated and dissimilar (see Table 1), and because compound familiarity failed to explain the priming effect, the integrative priming observed here cannot be explained by any extant model of lexical priming.

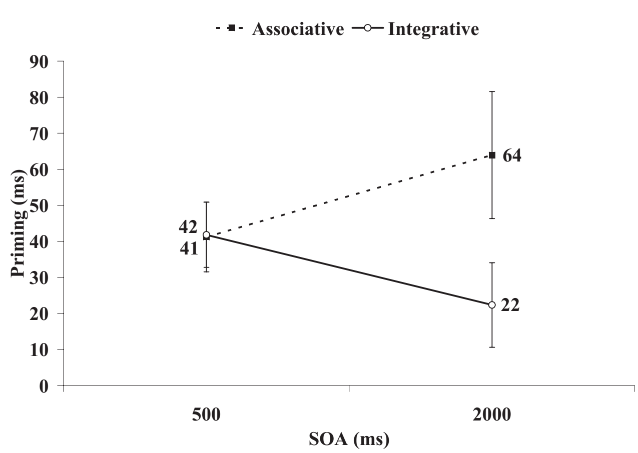

Figure 1. Associative and integrative priming ($M \pm SE$) as a function of stimulus onset asynchrony (SOA) in Experiment 1. Priming = Baseline RT – Experimental RT; positive values indicate facilitation.

Experiment 2

Whereas the preceding experiment dissociated integrative priming from associative priming, in Experiment 2 we compared integrative

Table 2
Response Times (in milliseconds) and Accuracy Rates (Proportion Correct) Across SOAs in Experiments 1 and 2

			SOA									
			100		500		1,500		2,000		2,500	
Experiment	Prime type	Measure	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
1	Baseline	RT			585	12			644	26		
		Accuracy			0.98	0.005			0.98	0.006		
	Associative	RT			543	15			580	18		
		Accuracy			0.99	0.004			0.99	0.004		
	Integrative	RT			543	14			622	25		
		Accuracy			0.98	0.005			0.98	0.007		
2	Baseline	RT	631	15	638	18	663	20			667	18
		Accuracy	0.99	0.004	0.99	0.005	0.99	0.004			0.99	0.004
	Semantic	RT	613	13	595	22	627	19			652	18
		Accuracy	0.99	0.005	0.99	0.003	0.99	0.003			0.99	0.004
	Integrative	RT	611	14	589	21	639	22			644	14
		Accuracy	0.98	0.005	0.98	0.005	0.99	0.003			0.99	0.004

Note. SOA = stimulus onset asynchrony; RT = response time.

priming with semantic priming. The same target words (e.g., *wine*) were preceded by either a baseline prime (i.e., ********), a semantic prime (e.g., *gin*), or an integrative prime (e.g., *box*). We also examined in greater detail the temporal dynamics of integrative priming. Of particular interest were earlier and later SOAs, which would indicate whether integrative priming occurs rapidly and/or persists late. In addition to the intermediate SOA of 500 ms, we also included a short SOA of 100 ms and two late SOAs of 1,500 ms and 2,500 ms. Thus, the experiment had a 3 (prime: baseline, semantic, integrative; within participants) × 4 (SOA: 100 ms, 500 ms, 1,500 ms, 2,500 ms; between participants) mixed design.

Method

Participants. One hundred seventy-five participants were randomly assigned to one of the four SOA conditions.

Stimuli. All experimental stimuli are reported in Appendix A, and stimulus characteristics are summarized in Table 1. Each of the 45 targets was paired with a semantic prime and an integrative prime. The targets were more similar to the semantic primes than to the integrative primes but were more easily integrated with the integrative primes than with the semantic primes (see Table 1). The semantic and integrative items were closely matched for both forward and backward association. The nonword targets were identical to those of Experiment 1.

Procedure. The procedure was identical to that of Experiment 1, except that the blank interval between prime offset and target onset was either 0 ms, 400 ms, 1,400 ms, or 2,400 ms, depending on the SOA condition (i.e., 100 ms, 500 ms, 1,500 ms, 2,500 ms).

Results and Discussion

Full results are presented in Table 2, and priming effects are illustrated in Figure 2. As evident in the figure, the temporal dynamics of integrative priming were similar to those of semantic priming. Both were evident at the early SOA (100 ms), peaked at the intermediate SOA (500 ms), and then dissipated across the later SOAs (1,500 ms and 2,500 ms). These results indicate that integrative priming, like semantic priming, emerges and dissipates rapidly.

We analyzed the data via a 3 (prime: baseline, semantic, integrative; within participants) × 4 (SOA: 100 ms, 500 ms, 1,500 ms, 2,500 ms; between participants) mixed ANOVA. Accuracy approached ceiling ($M = 0.99$, $SE = .002$) and produced no significant effects (all $ps > .19$). Relative to the baseline prime, semantic and integrative primes facilitated lexical decisions (see Figure 2), as indicated by a significant main effect of prime on response times, $F_p(2, 342) = 18.46$, $p < .001$; and, $F_i(1, 88) = 31.55$, $p < .001$. The main effect of SOA was significant across items, $F_i(3, 132) = 32.78$, $p < .001$, but not across participants, $F_p(3, 171) = 1.59$, $p = .19$. The interaction failed to approach significance (both $ps > .28$). This lack of interaction suggests that each of the three prime types produced similar response patterns across the various SOAs. This, in turn, indicates that integrative priming was not dissociated from semantic priming (see Figure 2). Indeed, paired comparisons of response times

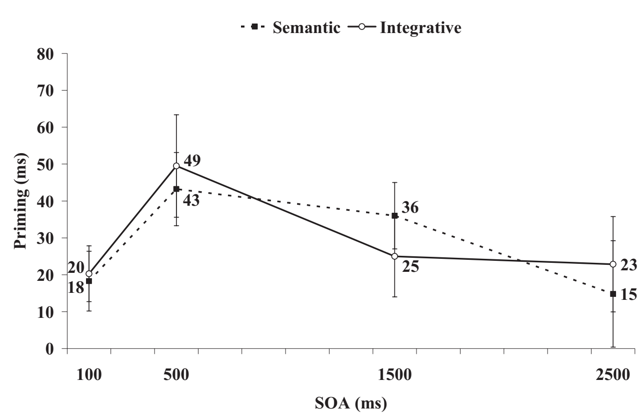

Figure 2. Semantic and integrative priming ($M \pm SE$) as a function of stimulus onset asynchrony (SOA) in Experiment 2. Priming = Baseline RT − Experimental RT; positive values indicate facilitation.

in the semantic and integrative conditions failed to approach significance within any of the four SOA conditions (all *p*s ≥ .20).

As in the preceding experiment, we also examined whether the integrative priming could be due to compound familiarity. However, familiarity ratings (see Experiment 1) did not correlate significantly with integrative priming ($r = +.03$, $p = .83$, collapsed across SOAs). Evidently, the integrative priming was not attributable to compound familiarity. So once again, because the integrative primes were unassociated with and dissimilar to their targets, and because compound familiarity was unrelated to response times, the integrative priming observed here cannot be explained by extant models of lexical priming.

Experiment 3A

In Experiment 3A, we investigated whether integrative priming is controlled or uncontrolled. The hallmark of a controlled process is that its efficacy for task performance modulates the magnitude of its effect: Controlled processes are more likely to occur when they are adaptive for the given task than when they are ill-adaptive. For instance, when the majority of prime words can be easily integrated with their target words, integration will be a successful strategy in the LDT. If the letter strings can be easily integrated, then the target must be a word. And if the letter strings cannot be easily integrated, then the target likely is a nonword. Thus, successful integration is highly predictive of the correct response. However, when relatively few of the prime words can be integrated with their target words, integration will be a poor strategy for the task. If the letter strings are not easily integrated, the target could be either a word or a nonword. So in this case, integration is not predictive of the correct response.

Coolen et al. (1991) conducted a preliminary investigation of the effect of RP on relational integration. In their first experiment, half (30 out of 60) of the critical trials could be easily integrated. In another experiment, they included as filler trials a large number of individual words and nonwords, but half (15 out of 30) of the critical word pairs were again easily integrated. They found an integration effect in both experiments. From this they concluded that integration is beyond strategic control. Unfortunately, however, that result is equivocal. In both of their experiments, successful integration of the critical word pairs was 50% predictive of a correct response (i.e., 30/60 and 15/30). The individual word and nonword fillers in their second experiment are irrelevant to the integration RP, because only word *pairs* can be integrated. Thus, their experiments do not constitute a clear manipulation of RP.

We therefore tested in Experiment 3A whether integrative priming is controlled or uncontrolled by manipulating RP. In addition to the experimental integrative stimuli, some participants also judged a number of filler word pairs that were easily integrated (.80 RP condition), whereas other participants judged filler pairs that were difficult to integrate (.20 RP condition) so that the proportion of integrative items varied across RP conditions. A 2 (prime: baseline, integrative; within participants) × 2 (RP: .20, .80; between participants) mixed design was thus used in the experiment. If relational integration is controlled, then the integrative priming effect should be larger in the .80 RP condition than in the .20 RP condition. Alternatively, if relational integration is uncontrolled, then integrative priming should be invariant across RPs. Because RP effects tend to occur with SOAs greater than 300 ms (Henik, Friedrich, Tzelgov, & Tramer, 1994; Hutchison, Neely, & Johnson, 2001; Perea & Rosa, 2002; Stolz, Besner, & Carr, 2005; Stolz & Neely, 1995), we used a 500-ms SOA.

Method

Participants. One hundred twenty-five undergraduates were randomly assigned to the .20 ($n = 63$) or the .80 ($n = 62$) RP condition.

Stimuli. The experimental stimuli were a subset of 30 items from those used in Experiments 1 and 2 (denoted with an asterisk in Appendix A). The integratability ($M = 5.42$, $SD = 0.82$), forward association ($M = 0.01$, $SD = 0.01$), backward association ($M = 0.00$, $SD = 0.01$), and similarity ($M = 2.04$, $SD = 0.66$) of this subset of stimuli were comparable to those of the entire stimulus set used in the preceding experiments (see Table 1, Integrative row). Items were rotated across experimental lists, such that 15 of the critical targets were preceded by their integrative prime (i.e., integrative condition), 15 targets were preceded by a row of eight asterisks (i.e., baseline condition), and no target appeared more than once.

In order to manipulate RP, we included filler stimuli that were either easy or difficult to integrate. *RP* is defined as the proportion of word → word trials in which the prime and target words are related (Neely et al., 1989; Tweedy et al., 1977). We counted integrative prime–target trials as "related" and nonintegrative prime–target trials as "unrelated." In the .80 RP condition, there were 45 integrative fillers (e.g., *tomato* → *soup*) and 15 nonintegrative fillers (e.g., *turnip* → *font*). Thus, each experimental list in the .80 RP condition included 15 critical integrative trials, 45 filler integrative trials, and 15 filler nonintegrative trials (RP = 60/75 = .80). In the .20 RP condition, there were 60 nonintegrative filler pairs. Thus, each experimental list in the .20 RP condition included 15 critical integrative trials and 60 filler nonintegrative trials (RP = 15/75 = .20). To confirm that the "integrative" fillers were highly integrative and that the "nonintegrative" fillers indeed were difficult to integrate, all filler pairs were rated for integratability ($N = 35$) following the "isolated" procedure of Experiment 1. The mean of the integrative fillers was 5.99 ($SD = 0.76$), thus confirming that they were highly integrative. The mean of the nonintegrative fillers was 2.08 ($SD = 0.60$), supporting the assumption that those items indeed were difficult to integrate. In both conditions, there were also 60 baseline fillers (e.g., ******** → *goose*) and 150 nonword targets, half of which were preceded by a prime word (e.g., *farm* → *ramus*) and half of which were preceded by the baseline prime (e.g., ******** → *revicle*). Thus, the experiment consisted of 300 trials presented in random order.

Procedure. The procedure was identical to the 500-ms SOA condition of the preceding experiments. Ten practice trials preceded the 300 experimental trials. There was a self-paced break midway through the experiment.

Results and Discussion

Full results are presented in Table 3, and priming effects are illustrated in Figure 3A. As evident in the figure, relational integration facilitated lexical processing, and this integrative priming effect was invariant across the .20 and the .80 RP conditions. This apparent lack of strategic mediation suggests that relational integration is uncontrolled.

Table 3
Response Times (in milliseconds) and Accuracy Rates (Proportion Correct) Across Experiments 3A, 3B, and 4

			RT		Accuracy	
Experiment	RP	Prime type	*M*	*SE*	*M*	*SE*
3A	0.20	Baseline	582	10	0.99	0.004
		Integrative	555	12	0.98	0.007
	0.80	Baseline	578	9	0.99	0.003
		Integrative	545	10	0.99	0.003
3B	0.20	Baseline	592	10	0.99	0.001
		Semantic	585	13	0.99	0.003
	0.80	Baseline	584	12	0.99	0.004
		Semantic	552	13	0.99	0.004
4	0.20	Baseline	559	10	0.99	0.004
		Integrative	545	9	0.99	0.004
	0.80	Baseline	563	11	0.99	0.003
		Integrative	547	10	0.99	0.003

Note. RT = response time; RP = relatedness proportion.

We analyzed the data via 2 (prime: baseline, integrative; within participants) × 2 (RP: .20, .80; between participants) mixed ANOVA. Accuracy was near ceiling ($M = 0.99$, $SE = .003$) and exhibited no significant effects (all *p*s > .25). The targets elicited faster lexical decisions after an integrative prime ($M = 550$, $SE = 8$) than after a baseline prime ($M = 580$, $SE = 7$), $F_p(1, 123) = 30.71$, $p < .001$; and, $F_i(1, 29) = 48.16$, $p < .001$. Consistent with the preceding experiments, the present result demonstrates that the effect of relational integration indeed is facilitative. There was no indication that RP modulates integrative priming, as neither the main effect of RP, $F_p(1, 123) = 0.27$, $p = .60$; and, $F_i(1, 29) = 3.73$, $p = .06$, nor its interaction with prime was significant, $F_p(1, 123) = 0.31$, $p = .58$; and, $F_i(1, 29) = 0.25$, $p = .62$. Moreover, paired comparisons confirmed that the integrative priming effect was significant in both the .20 RP condition, $t_p(62) = 3.23$, $p < .01$; and, $t_i(29) = 3.64$, $p < .01$, and the .80 RP condition, $t_p(61) = 4.82$, $p < .001$; and, $t_i(29) = 3.97$, $p < .001$. Once again, compound familiarity was unrelated to the magnitude of integrative priming ($r = -.27$, $p = .15$, collapsed across RPs).

These results suggest that relational integration is uncontrolled. If relational integration were controlled or adaptable, then this strategy should be used more often when the majority of word pairs are easily integrated than when they are not. Thus, the integrative priming effect should have been larger in the .80 RP condition than in the .20 RP condition. Indeed, the integration strategy would be ill-adaptive when only 20% of the word targets (and only 10% of all trials) could be integrated. Yet, integrative priming was just as prevalent and just as sizable in the .20 condition as in the .80 condition, presumably because relational integration is beyond strategic control.

Experiment 3B

Although we have attributed the absence of an RP effect in Experiment 3A to a lack of strategic control of relational integration, it could be due alternatively to some unknown methodological factor. To test this explanation, Experiment 3B was an exact replication of Experiment 3A, except that the integrative primes were replaced by semantic primes. Because semantic priming is under strategic control, it is sensitive to manipulations of RP (Hutchison, 2007; Neely et al., 1989). We therefore expected a significant RP effect in the present experiment. If obtained, this would demonstrate that the null RP effect of the preceding experiment was not due to methodological factors.

Method

Participants. One hundred forty undergraduates were randomly assigned to the .20 ($n = 70$) or the .80 ($n = 70$) RP condition.

Stimuli. Stimuli consisted of experimental prime–target pairs that were similar, filler pairs that were either highly similar or dissimilar (in the different RP conditions), and filler pairs that had a nonword target. The 30 experimental targets used in Experiment 3A were paired with semantic primes here in Experiment 3B (see Appendix A). The integratability ($M = 3.06$, $SD = 0.80$), forward association ($M = 0.03$, $SD = 0.03$), backward association ($M = 0.01$, $SD = 0.03$), and similarity ($M = 4.54$, $SD = 0.86$) of this subset of stimuli were comparable to those of the entire stimulus set used in Experiment 2 (see Table 1, Semantic row). The proportions of items in the .20 and .80 conditions paralleled those of Experiment 3A, with 45 highly similar filler items (e.g., *robin* → *canary*) taken from Lupker (1984), McRae and Boisvert (1998), and Moss et al. (1995). The pairs with a nonword target were the same as in Experiment 3A.

Procedure. The procedure was identical to Experiment 3A.

Results and Discussion

Unlike integrative priming (see Figure 3A), semantic priming was modulated by the proportion of related primes and targets (see Figure 3B). This RP modulation corroborates prior demonstrations that semantic priming is under strategic control (Hutchison, 2007; Neely et al., 1989) and suggests that the lack of RP modulation in Experiment 3A was not due to spurious methodological factors. Full results are presented in Table 3, and priming effects are illustrated in Figure 3B.

We analyzed the data via a 2 (prime: baseline, semantic; within participants) × 2 (RP: .20, .80; between participants) mixed

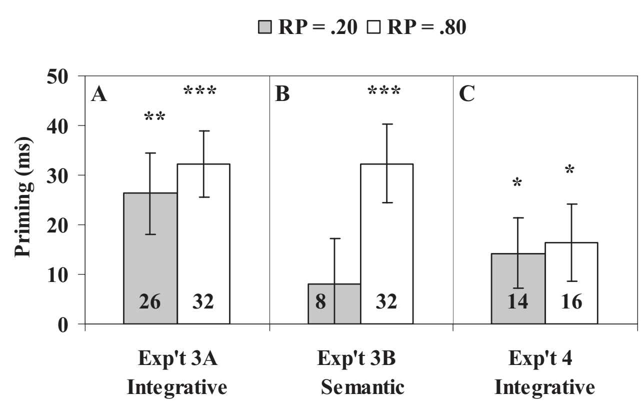

Figure 3. Integrative and semantic priming ($M \pm SE$) as a function of relatedness proportion (RP) in Experiments 3A (**A**), 3B (**B**), and 4 (**C**). Priming = Baseline RT − Experimental RT; positive values indicate facilitation. * $p < .05$. ** $p < .01$. *** $p < .001$.

ANOVA. Analysis of accuracy rates revealed only a main effect of RP, $F_p(2, 120) = 3.61$, $p < .05$; and, $F_i(1, 29) = 4.57$, $p < .05$, with higher accuracies in the .20 RP condition ($M = 0.995$, $SE = 0.002$) than in the .80 RP condition ($M = 0.988$, $SE = 0.002$).

The targets elicited faster lexical decisions after a semantic prime ($M = 568$, $SE = 9$) than after a baseline prime ($M = 588$, $SE = 8$), $F_p(1, 138) = 11.10$, $p = .001$; and, $F_i(1, 29) = 14.98$, $p = .001$. The main effect of RP was reliable by items, $F_i(1, 29) = 21.68$, $p < .001$, but not by participants, $F_p(1, 138) = 1.70$, $p = .19$. Most important, however, RP modulated semantic priming (see Figure 3B): The RP × Prime interaction was significant, $F_p(1, 138) = 4.05$, $p < .05$; and, $F_i(1, 29) = 6.73$, $p < .05$, and paired comparisons confirmed that the semantic priming effect was significant in the .80 RP condition, $t_p(69) = 4.10$, $p < .001$; and, $t_i(29) = 4.46$, $p < .001$, but not in the .20 RP condition, $t_p(69) = 0.87$, $p = .39$; and, $t_i(29) = 1.05$, $p = .30$. This finding replicates previous findings of an RP effect on semantic priming (e.g., Hutchison, 2007; Neely et al., 1989).

Given that the relation between prime and target words was the only systematic difference between Experiments 3A (integrative) and 3B (semantic), the lack of RP effect with integrative primes in Experiment 3A evidently was not attributable to procedural factors. Collectively, Experiments 3A and 3B thus provide suggestive evidence of a dissociation of integrative priming and semantic priming. Whereas semantic priming is subject to strategic control, integrative priming appears to be uncontrolled.

Experiment 4

Experiment 4 replicated Experiment 3A, but with a different baseline condition and different measures of compound familiarity. In studies of lexical priming, there is no universally accepted baseline condition. The use of neutral symbols (e.g., ******** or XXXXXXXX) is common but may be criticized for not engaging the lexical system, not controlling lexical processing, and/or not maintaining attention on the task. Consequently, any observed difference between such a neutral baseline condition and an experimental word prime condition may be attributed to any of these factors. Or to state it more concretely, the faster responding after an integrative prime than after a neutral prime could reflect a response delay from the neutral primes rather than a response facilitation from the integrative primes. These criticisms suggest the use of unrelated words as primes, and indeed this is another common baseline condition (see Hutchison, 2003, Table 2). However, this approach may be criticized too, as an unrelated prime may actually interfere with the process of interest. For example, faster responding after an integrative prime than after an unrelated word prime could be due either to facilitation via integration or to interference from the unrelated word. The most conservative approach, then, is to use both types of baseline. Given that the preceding experiments have demonstrated integrative priming relative to a neutral baseline (i.e., ******** → *wine*), in Experiment 4 we tested for integrative priming relative to an unrelated word baseline (e.g., *copper* → *wine*).

Experiment 4 also included different measures of the compound familiarity of the prime–target pairs. In Experiments 1, 2, and 3A, we reported that participants' familiarity ratings did not correlate with the magnitude of integrative priming. However, McKoon and Ratcliff (1992) noted that subjective ratings may not provide the best measure of familiarity. They argued that the frequency of co-occurrence in large samples of written language provides the best estimate of prime–target familiarity. Thus, in order to reject more conclusively a compound familiarity explanation of integrative priming, in Experiment 4 we measured compound familiarity in terms of both local and global co-occurrence. Local co-occurrence is the frequency with which two words occur directly adjacent to one another in a large text corpus, whereas global co-occurrence is the frequency with which two words occur in the same or similar documents within a large text corpus. In Experiment 4, we measured local co-occurrence via Google hits (i.e., the number of occurrences of the given noun compound in the Google Internet search engine), which have been shown to predict comprehension times of noun compounds (Wisniewski & Murphy, 2005). We measured global co-occurrence via latent semantic analysis (LSA; Landauer & Dumais, 1997).

We also examined whether local and global co-occurrence were related to integrative priming in the preceding experiments. For this analysis, we used the 30 integrative prime–target pairs that were common to Experiments 1, 2, and 3A, and we collapsed across SOAs in Experiment 2 and across RPs in Experiment 3A because those factors did not interact with prime type. Google hits and LSA values were both positively skewed, so both were log transformed for normalization. Importantly, both Google hits and LSA values diverged from familiarity ratings: Familiarity ratings were only moderately related to Google hits ($r = +.40$, $p < .05$), and were unrelated to LSA values ($r = +.07$, $p = .73$). Moreover, Google hits and LSA values were also unrelated to one another ($r = +.19$, $p = .31$). Given the divergence of these three measures of familiarity, it is feasible that local co-occurrence (Google hits) and/or global co-occurrence (LSA values) could explain the observed integrative priming even though subjective familiarity (participant ratings) did not. In fact, though, none of the three measures was significantly correlated with the magnitude of integrative priming in either Experiment 1 (either SOA condition), Experiment 2, or Experiment 3A (all *p*s ≥ .10). Nevertheless, given the suggestion that compound familiarity is best measured by co-occurrence (McKoon & Ratcliff, 1992), we included both Google hits and LSA values as controls for compound familiarity here in Experiment 4.

Finally, Experiment 4 also replicated the RP manipulation of Experiment 3A, but for purposes of generality, we used a different stimulus set. Thus, the experiment had a 2 (prime: baseline, integrative; within participants) × 2 (RP: .20, .80; between participants) mixed design. A larger priming effect in the .80 RP condition than in the .20 RP condition would indicate that relational integration is controlled, whereas a priming effect that is invariant across RPs would suggest that relational integration is uncontrolled.

Method

Participants. One-hundred four undergraduates were randomly assigned to the .20 ($n = 53$) or the .80 ($n = 51$) RP condition. An additional 25 undergraduates participated in an integratability rating task.

Stimuli. Integrative stimuli (see Appendix B) consisted of 10 prime–target pairs from Experiment 3A (e.g., *winter* → *sport*) and 20 new pairs (e.g., *stable* → *cow*). The unrelated baseline pairs were created by re-pairing the 30 integrative primes with other targets (e.g., *winter* → *cow*), such that the global co-occurrence (i.e., LSA cosine) of each integrative pair was matched as closely as possible to its corresponding unrelated pair. Thus, the integrative ($M = 0.08$, $SD = 0.04$) and unrelated pairs ($M = 0.08$, $SD = 0.05$) did not differ in global co-occurrence. They did differ in local co-occurrence, however: Log Google hits (as sampled on August 24, 2008) were greater for integrative pairs ($M = 5.15$, $SD = 1.22$) than for unrelated pairs ($M = 3.95$, $SD = 1.21$). This conflation of local co-occurrence and prime type is addressed in the *Results* section below. The unrelated pairs were strictly unassociated ($M = 0.00$), and the integrative pairs were virtually unassociated (forward $M = 0.01$, $SD = 0.01$; backward $M = 0.00$, $SD = 0.01$).

Twenty-five participants rated the integratability of the stimuli on a scale ranging from 1 to 7 (see the *Stimuli* section in Experiment 1 for details on the "isolated" rating task). The 60 prime–target pairs were balanced and rotated across two lists so that each participant rated 15 integrative pairs and 15 unrelated pairs, and each participant rated each target only once. Ratings confirmed that the integrative pairs ($M = 5.06$, $SD = 1.22$) were easier to integrate than the unrelated pairs ($M = 2.18$, $SD = 0.94$). Although the ranges for the integrative (2.28–6.64) and unrelated pairs (1.16–4.84) overlapped, 29 of the 30 targets were more easily integrated with their integrative prime than with their unrelated prime. One target was integrated marginally more easily with its unrelated prime (*chain island* = 2.96) than with its integrative prime (*monkey island* = 2.28).

Filler stimuli were taken from Experiment 3A. The .20 RP condition included 45 nonintegrative fillers (integratability $M = 2.10$, $SD = 0.62$), whereas the .80 RP condition included 45 integrative fillers ($M = 5.96$, $SD = 0.76$).

Procedure. The procedure was the same as Experiment 3A.

Results and Discussion

Full results are presented in Table 3, and priming effects are illustrated in Figure 3C. Results replicated Experiment 3A: Relational integration facilitated lexical decisions, and this integrative priming effect was invariant across the .20 and the .80 RP conditions (see Figure 3C).

We analyzed the data by a 2 (prime: baseline, integrative; within participants) × 2 (RP: .20, .80; between participants) mixed ANOVA. Accuracy rates exhibited only a main effect of RP that was significant across items, $F_i(1, 29) = 47.21$, $p < .001$, such that accuracy was higher in the .80 RP condition ($M = 0.99$, $SE < 0.01$) than in the .20 RP condition ($M = 0.97$, $SE = 0.01$). However, this effect was not significant across participants, $F_p(1, 102) = 0.73$, $p = .40$. Responses were a reliable 15 ms faster after the integrative primes ($M = 546$, $SE = 7$) than after the unrelated baseline primes ($M = 561$, $SE = 8$), $F_p(1, 102) = 8.40$, $p < .01$; and, $F_i(1, 29) = 20.83$, $p < .001$. Neither the main effect of RP, $F_p(1, 102) = 0.05$, $p = .82$; and, $F_i(1, 29) = 1.06$, $p = .31$, nor its interaction with prime, $F_p(1, 102) = 0.04$, $p = .84$; and, $F_i(1, 29) = 0.13$, $p = .72$, approached significance. Paired comparisons revealed significant integrative priming in both the .20 RP condition, $t_p(52) = 2.00$, $p = .05$; and, $t_i(29) = 2.80$, $p < .01$, and the .80 RP condition, $t_p(50) = 2.09$, $p < .05$; and, $t_i(29) = 3.30$, $p < .01$. Thus, as in Experiment 3A, RP did not modulate integrative priming.

Although the integrative and the unrelated word pairs were matched closely for association and global co-occurrence (LSA values), recall that local co-occurrence (Google hits) was greater among integrative pairs than among unrelated pairs. We therefore tested for a relation between local co-occurrence and integrative priming in two ways. First we tested whether the difference in local co-occurrence (i.e., $\text{Google}_{\text{integrative}} - \text{Google}_{\text{unrelated}}$) predicted the magnitude of integrative priming (i.e., $\text{RT}_{\text{unrelated}} - \text{RT}_{\text{integrative}}$). It did not ($r = -.07$, $p = .73$). Second, we also tested whether local co-occurrence of the integrative pairs (i.e., $\text{Google}_{\text{integrative}}$) moderated the magnitude of integrative priming (i.e., $\text{RT}_{\text{unrelated}} - \text{RT}_{\text{integrative}}$). It did ($r = -.37$, $p < .05$), but this relationship was the opposite of what the compound cue model would predict. That is, more familiar integrative compounds such as *pool party* (log Google = 6.82) exhibited less integrative priming than unfamiliar integrative compounds such as *lecture sleep* (log Google = 2.87). To examine this relationship more closely, we performed a median split on the local co-occurrence of the integrative pairs, and then we tested whether highly familiar and less familiar compounds exhibited integrative priming separately. Although the integrative priming effect was twice as large among less familiar compounds ($M = 20$, $SE = 6$) as among more familiar compounds ($M = 10$, $SE = 3$), both groups of compounds nonetheless exhibited significant integrative priming, unfamiliar $t(14) = 3.61$, $p < .01$; familiar $t(14) = 3.18$, $p < .01$. In summary, local co-occurrence did moderate the magnitude of integrative priming, but there appears to be more to integrative priming than just local co-occurrence.

Given that only the stimuli differed between Experiments 3A and 4, we conducted further analyses across participants from both of these experiments combined ($N = 229$). A 2 (prime: baseline, integrative; within participants) × 2 (RP: .20, .80; between participants) × 2 (Experiment: 3A, 4; between participants) mixed ANOVA revealed no effects in the accuracy data. However, lexical decisions to targets were significantly faster following an integrative prime ($M = 548$, $SE = 5$) than following a baseline prime ($M = 571$, $SE = 5$), $F_p(1, 225) = 35.02$, $p < .001$. The Prime × Experiment interaction approached significance, $F_p(1, 225) = 3.45$, $p = .065$. Table 3 reveals that this near interaction was attributable to the baseline conditions: Targets elicited slower responses after the neutral baseline prime (Experiment 3A) than after an unrelated word prime (Experiment 4). Target responses following an integrative prime, in contrast, were equally fast across experiments. Most critically, the effect of RP once again failed to approach significance, $F_p(1, 225) = 0.04$, $p = .84$. Across experiments, integrative priming was significant in both the .20 RP condition ($M = 21$, $SE = 6$), $t_p(115) = 3.78$, $p < .001$, and the .80 RP condition ($M = 25$, $SE = 5$), $t_p(112) = 4.89$, $p < .001$. No other main effect or interaction was significant (all ps $> .24$).

Three aspects of this result are notable. First, given that integrative primes have elicited faster responses than both neutral symbol primes (Experiment 3A) and unrelated word primes (Experiment 4), it appears unequivocal that relational integration facilitates lexical decisions. Second, given that neither local co-occurrence nor global co-occurrence explained integrative priming (see McKoon & Ratcliff, 1992), the integrative priming effect cannot be attributed to compound familiarity. Finally, the equivalent magnitude of integrative priming across the high- and low-RP conditions corroborates the conclusion that relational integration is uncontrolled.[3] So whereas semantic priming is modulated by RP (Experiment 3B; see also Hutchison, 2007), integrative priming is unaffected by RP (Experiments 3A and 4). This result constitutes a dissociation of semantic priming and integrative priming, albeit between experiments.

General Discussion

These experiments provide the first unequivocal demonstration that relational integration facilitates lexical processing. Across experiments, lexical decisions for the exact same target words were faster when preceded by a prime word with which they could be easily integrated into a sensible phrase (e.g., *box* → *wine*) than when preceded by a neutral baseline prime (e.g., ****** → *wine*) or an unrelated word prime (e.g., *copper* → *wine*). A variable prime–target SOA was used in Experiments 1 and 2 to compare the temporal dynamics of this integrative priming (e.g., *box* → *wine*) with those of associative priming (e.g., *cork* → *wine*) and semantic priming (e.g., *gin* → *wine*). Integrative priming was dissociated from associative priming at a 2,000-ms SOA (Experiment 1) but closely resembled semantic priming from early (100-ms) to late (2,500-ms) SOAs (Experiment 2). Like semantic priming, integrative priming emerged rapidly and asymptoted early. Experiments 3A and 4 demonstrated that, unlike semantic priming (Experiment 3B), integrative priming is uncontrollable: Integrative priming was consistent across low- (.20) and high- (.80) RP conditions. In summary, then, relational integration produced rapid and uncontrollable integrative priming among concepts that are dissimilar and unassociated and that are unfamiliar as a phrase.

Extant Models of Lexical Priming

These results are not explicable via any extant model of lexical priming. Because the integrative prime–target pairs were unassociated, dissimilar, and unfamiliar, the observed integrative priming cannot be attributed to associative strength, featural similarity, or compound familiarity. Consider the concepts *monkey* and *foot*. When given *monkey* as a cue word in the free-association task, participants rarely if ever produce *foot* in response. The two concepts do not share many features, they do not form a familiar compound, and they do not co-occur frequently in ordinary language. Yet, *monkey* facilitates lexical processing of *foot*. Clearly, any model that ascribes lexical priming to association, similarity, or familiarity (e.g., spreading activation, distributed representation, expectancy, semantic matching, episodic retrieval, compound cue) fails to explain the priming that occurs with these and other integrative concepts. To be clear, we are not suggesting that the extant models be rejected as generally incorrect or inapplicable to priming phenomena. On the contrary, these models were entertained precisely because their viability is widely supported by prior studies. Our claim is simply that *integrative priming*, in particular, is not explained by any of these models. Under the present conditions, some other mechanism must explain the priming. The most likely and natural explanation is that the prime and target concepts are easily integrated into a sensible compound representation and that this relational integration occurs rapidly and uncontrollably during lexical processing (see also Coolen et al., 1991; Seidenberg et al., 1984). Below we consider some basic cognitive mechanisms that, in light of the present results, could explain how integrative priming occurs. First, however, we consider the reliability of integrative priming across individuals.

Individual Differences in Integrative Priming

Stolz et al. (2005) conducted an in-depth investigation of the reliability of semantic priming across participants and across items (see also Hutchison et al., 2008). They orthogonally crossed SOA (200 ms, 350 ms, 800 ms) and RP (.25, .50, .75), testing a total of 720 individuals. Stolz and colleagues found that, overall, about 15% of participants exhibited no semantic priming. Although the present experiments were not designed for this purpose, we nonetheless examined priming effects at the level of individual participants. For each participant, we compared the mean response time in the experimental conditions (e.g., integrative, associative, semantic) with the mean response time in the baseline condition to determine whether the experimental primes facilitated target word recognition (i.e., priming). Table 4 shows descriptive statistics in terms of both prevalence (i.e., percentage of participants exhibiting a priming effect) and magnitude (i.e., effect size among those participants) in each of the experiments separately.

In Experiment 1, 81% of participants exhibited associative priming, 74% exhibited integrative priming, and 65% exhibited both integrative and associative priming. This finding suggests that most participants engaged in multiple retrieval processes simultaneously; the processes that yield integrative priming and associative priming are not mutually exclusive. The prevalence of associative priming was constant at 81% across both the 500-ms and 2,000-ms SOA conditions. Thus, the increase in associative priming across SOAs (see Figure 1) was due to an increase in magnitude rather than prevalence. That is, of the participants who exhibited associative priming, the mean effect size increased from 58 ms in the 500-ms SOA condition to 91 ms in the 2,000-ms SOA condition. In contrast, the diminution of the integrative priming effect across SOAs (see Figure 1) was due to a decrease in prevalence rather than magnitude. Within the 500-ms and 2,000-ms SOA conditions, 81% and 68% of participants, respectively, exhibited integrative priming. Of the participants who exhibited integrative priming, the mean effect sizes were 57 ms and 56 ms in the 500-ms and 2,000-ms SOA conditions, respectively. Because fewer participants exhibited this priming effect in the 2,000-ms SOA condition than in the 500-ms SOA condition, the overall magnitude of the priming effect diminished across SOAs.

In Experiment 2, 66% and 63% of participants, respectively, exhibited semantic priming and integrative priming, with 52% exhibiting both types of priming. Across the increasing SOAs, both types of priming exhibited an initial increase and a subsequent decrease in both prevalence and magnitude. This pattern corroborates that observed in overall response times (see Figure 2).

In Experiment 3A, 72% of participants exhibited integrative priming, with a mean magnitude of 54 ms. The prevalence and magnitude of integrative priming were virtually identical across

[3] Of course, because it rests on a null difference between the high- and low-RP conditions, this conclusion is necessarily tentative. However, it should also be noted that the we did use a standard method (i.e., LDT) with large samples, which yielded a highly significant effect of integrative priming. So, if there is any effect of RP on integrative priming, then it would appear to be rather subtle.

Table 4
Prevalence and Magnitude of Priming Effects Across Experiments

Experiment	Prime type	SOA	RP	Prevalence	Magnitude
1	Integrative	500	1.00	81%	57 ms
		2,000	1.00	68%	56 ms
			Total	74%	57 ms
	Associative	500	1.00	81%	58 ms
		2,000	1.00	81%	91 ms
			Total	81%	74 ms
2	Integrative	100	1.00	60%	53 ms
		500	1.00	76%	86 ms
		1,500	1.00	60%	73 ms
		2,500	1.00	56%	74 ms
			Total	63%	72 ms
	Semantic	100	1.00	65%	44 ms
		500	1.00	71%	74 ms
		1,500	1.00	73%	58 ms
		2,500	1.00	56%	75 ms
			Total	66%	62 ms
3A	Integrative	500	0.20	73%	51 ms
		500	0.80	71%	58 ms
			Total	72%	54 ms
3B	Semantic	500	0.20	56%	51 ms
		500	0.80	74%	60 ms
			Total	65%	56 ms
4	Integrative	500	0.20	62%	44 ms
		500	0.80	63%	48 ms
			Total	**63%**	46 ms

Note. Prevalence is the percentage of participants who exhibited a priming effect (i.e., Baseline RT – Experimental RT > 0). Magnitude is the mean size of the priming effect (i.e., Baseline RT – Experimental RT) among those participants who exhibited priming. SOA = stimulus onset asynchrony; RP = relatedness proportion.

the .20 and .80 RP conditions. In Experiment 3B, 65% of participants exhibited semantic priming, with a mean magnitude of 56 ms. Unlike integrative priming, however, semantic priming was weaker in the .20 RP condition (56%, 51 ms) than in the .80 RP condition (74%, 60 ms). This result corroborates the effect of RP on semantic priming observed in the overall means (see Figure 3B). In Experiment 4, 63% of participants exhibited integrative priming, with a mean magnitude of 46 ms. The prevalence and magnitude of integrative priming again were virtually identical across the .20 RP condition and the .80 RP condition. Thus, in both Experiments 3A and 4, individual patterns of integrative priming were relatively constant across the RP manipulation. Experiment 3B, in contrast, revealed individual patterns of semantic priming that varied across RPs. This result suggests that integrative priming is uncontrolled, whereas semantic priming is controlled.

Across all experiments, we tested 606 participants for integrative, associative, and/or semantic priming. To compare the overall prevalence and magnitude of these different types of priming, we collapsed across all experiments. Of the 466 participants tested for integrative priming, 311 exhibited positive priming (67%), with a mean magnitude of 59 ms. Of the 315 who were tested for semantic priming, 207 exhibited positive priming (66%), with a mean magnitude of 60 ms. And of the 62 who were tested for associative priming, 50 exhibited positive priming (81%), with a mean magnitude of 74 ms. Integrative priming thus appears to be about as robust as semantic priming, and only slightly less robust than associative priming. Considering that integrative priming has been largely overlooked by cognitive psychologists, this is quite a striking observation.

An important goal for further study is to determine what participant factors contribute to integrative priming. The magnitude of semantic priming is predicted by an individual's perceptual ability (Plaut & Booth, 2000), attentional control (Hutchison, 2007), working memory capacity (Kiefer, Ahlegian, & Spitzer, 2005; Woltz & Was, 2007), and reading skill (Nation & Snowling, 1999). It seems likely that these same factors may also predict the magnitude of integrative priming. Consider, for example, working memory. In text comprehension, integrating a word into a larger context relies specifically on the verbal or semantic component of working memory rather than the phonological or spatial component (Fedorenko, Gibson, & Rohde, 2007; Haarmann, Davelaar, & Usher, 2003; Nation, Adams, Bowyer-Crane, & Snowling, 1999). Verbal-semantic working memory thus may predict integrative priming as well. Once the participant factors contributing to integrative priming are identified, it will be important to test whether those factors are malleable. If they are, then training programs to improve those critical skills potentially could improve an individual's language comprehension abilities more generally.

Possible Models of Integrative Priming

In the introduction, we alluded to basic cognitive mechanisms that might explain integrative priming. One possibility is to attribute integrative priming to a retrospective "integration check," whereby participants check whether the target can be integrated with the prime. If prime and target can be integrated, then the target must be a word. But if prime and target cannot be integrated, then the target could be either a word or a nonword. Hence, target words would elicit faster "word" responses when they are easily integrated with their prime than when not. Such an integration check is closely reminiscent of semantic matching, whereby participants check whether the target is associatively or semantically related to the prime. Indeed, it is tempting to simply include integratability as a third factor affecting the semantic matching process, so as to account for the priming observed among unassociated and dissimilar concepts in the present study. But the results of Experiments 3A and 4 indicate that integration checking and semantic matching are qualitatively different phenomena: Whereas semantic matching is controlled (Hutchison, 2007), integration checking is uncontrolled. A more general and serious limitation of the integration checking hypothesis is that it is more descriptive than explanatory. How exactly does one determine whether a target can be integrated with its prime, and how does this facilitate lexical processing? A more specific cognitive mechanism is required.

In introducing integrative priming, we have focused on relational integration. Implicit and essential to this relational integration, though, is a process of role assignment. That is, relational integration entails not only inferring a likely relation between concepts but also assigning those concepts to complementary semantic roles (Cohen & Murphy, 1984; Estes, 2003a; M. Jones & Love, 2007; Wisniewski, 1997; Wisniewski & Bassok, 1999;

Wisniewski & Love, 1998).[4] In *table vase*, for example, the table is a *location* and the vase is the *object*. To see why this role resolution is critical, consider the compounds *wind erosion* and *growth hormone*. Although both invoke a causal relation, notice that the *cause* occurs as modifier in the former and as head in the latter. Thus, simply inferring a sensible relation is insufficient for comprehension; one must also resolve which concepts perform which roles (Estes & Jones, 2008). Consequently, the same pair of concepts can be integrated more easily in one direction (e.g., *horse doctor*) than the other (e.g., *doctor horse*; L. L. Jones, Estes & Marsh, 2008), and integrative priming may differ accordingly.

Relational integration thus may be conceived as the resolution of a relational argument via binding of filler concepts to their respective relational roles. The following speculations about possible mechanisms of integrative priming are based on Hummel and Holyoak's (1997, 2003) model of relational concepts, which was substantially revised and extended by Doumas, Hummel, and Sandhofer (2008). A critical component of the model is that it contains semantic units not only for object concepts but also for the relational roles that those objects fill. To illustrate how this model might be extended to integrative priming, consider the noun compound *forest bird*, which is understood by inferring a *location* relation that entails the roles of *locale* and *object*. Abstractly speaking, integrative priming would occur when the prime and target words (e.g., *forest* and *bird*) are easily assigned to complementary roles in a semantic relation (i.e., *locale* and *object*, respectively). Basic mechanisms that might facilitate role assignment are described next.

Noun concepts appear to be associated with the integrative relations that they most frequently instantiate. For example, *forest* frequently instantiates the *location* relation (e.g., *forest bird*, *forest stream*). As a result of this association, noun compounds are understood faster if they instantiate a relation that is frequent for the given modifier (e.g., *forest bird*) than if they instantiate a relation that is infrequent for that concept (e.g., *forest story*; Gagné & Shoben, 1997; Storms & Wisniewski, 2005; but see Maguire, Devereux, Costello, & Cater, 2007; Wisniewski & Murphy, 2005). Note that this relation frequency effect can be interpreted alternatively as a role typicality effect: That is, nouns (e.g., *forest*) are associated with the semantic roles that they frequently instantiate (i.e., *locale*), and comprehension is facilitated when the given noun performs its typical role (e.g., *forest bird*). If one assumes that relational roles activate their complement—for example, *locale* activates *object*—then integrative priming could occur prospectively (i.e., prelexically), in that the prime preactivates the target before the target's actual presentation. By this model, integrative priming occurs because the prime word (*forest*) activates its typical role (*locale*), which in turn activates its complementary role (*object*), which then activates a set of typical fillers of that role (e.g., *bird*, *stream*, and the like). Lexical decisions are facilitated for target words that are typical of the complementary role. Alternatively, integrative priming could occur retrospectively (i.e., postlexically), in that the prime affects the target only after the target's presentation. By this model, the prime activates its typical role and its complementary role, and then one retrospectively evaluates whether the target could plausibly perform that complementary role (e.g., whether a bird can have a *location*). Thus, the critical difference between the prospective and retrospective variants of the model arises at the point when the complementary role concept is activated.

Although little is known about role assignment in noun compounds, indirect evidence from participle–noun phrases indicates that role typicality is critical. For instance, *arresting cop* is understood faster than *arrested cop*, because cops more typically perform the *arrester* role than the *arrestee* role. Conversely, *arrested crook* is understood faster than *arresting crook* because crooks are more typically *arrestees* than *arresters* (Ferretti, Gagne, & McRae, 2003; see also Ferretti, Kutas, & McRae, 2007; Ferretti, McRae, & Hatherell, 2001; McRae, Spivey-Knowlton, & Tanenhaus, 1998). Such lexical priming has been obtained in a naming task (Ferretti et al., 2007), which is traditionally viewed as an indicator of a prospective mechanism. Sentential contexts, however, elicit lexical priming to the extent that the sentence prime predicts the target word (see Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007; Schwanenflugel & LaCount, 1988). For example, "John went to the library to check out a . . . " facilitates recognition of the word *book*, but "John went to the store to buy a . . . " does not facilitate recognition of *book*. In terms of integrative priming, this result raises the question of whether modifiers such as *forest* are constraining enough to elicit priming prospectively. Some modifiers (e.g., *forest* . . .) have a vast number of plausible complements, whereas others seem to be more constraining (e.g., *race* . . .). This degree of constraint may affect the likelihood and/or magnitude of integrative priming. There is a clear need for analogous studies with noun compounds to determine whether the integrative priming demonstrated here does occur prospectively. However, it should be noted that prospective and retrospective processes both operate during lexical processing (Neely & Keefe, 1989), so any evidence of a prospective component to integrative priming would not exclude the possibility of an additional retrospective component.

The retrospective model raises a further question of how one determines whether a concept (e.g., *bird*) can plausibly perform a given role (e.g., *object*). Wisniewski and Murphy (2005) found that the time required to comprehend an integrative noun compound was predicted by the plausibility of its referent. Critically, though, researchers disagree about what plausibility is (e.g., Gagné & Spalding, 2006; Murphy & Wisniewski, 2006; see also Costello & Keane, 2000; L. L. Jones et al., 2008). Connell and Keane (2006), who tested the common assumption that something is plausible if it is consistent with prior knowledge, concluded that "a highly plausible scenario is one that fits prior knowledge (a) with many different sources of corroboration, (b) without complex explanation, and (c) with minimal conjecture" (p. 117; see also Connell & Keane, 2004; Murphy & Wisniewski, 2006). Although Connell and Keane investigated the plausibility of sentence pairs, their conclusions nonetheless may provide a useful framework for future investigation into the plausibility of noun compounds.

To complicate matters further, plausibility is practically similar to familiarity—Wisniewski and Murphy (2005) found a correlation of $\geq$ .90—but they are conceptually distinct constructs (Murphy & Wisniewski, 2006). Whereas *plausibility* reflects the ease with which

[4] Models vary dramatically in the number and specificity of semantic roles. Take for example the verb *sell*, which is a relational concept that entails two roles. These roles could be represented abstractly via protoroles like *agent* and *patient* (Dowty, 1991) or quite specifically as *jeweler* and *jewel wearer* (see Gildea & Jurafsky, 2002). An emerging consensus is that role representations are of more intermediate specificity (e.g., Ferretti et al., 2001; Gildea & Jurafsky, 2002; M. Jones & Love, 2007), in this example, perhaps like *salesperson* and *purchaser*.

one can imagine the referent of the combination, *familiarity* refers to its frequency of actual occurrence. For example, *office plant* and *prison plant* may be equally plausible, but for most readers, the former is more familiar. Our experiments have shown that familiarity is not necessary for integrative priming to occur, but in Experiment 4, familiarity did modulate the magnitude of integrative priming. Specifically, familiar compounds (e.g., *office plant*) exhibited less integrative priming than unfamiliar word pairs (e.g., *prison plant*). It may be that more familiar word pairs are indeed retrieved by compound cueing, as argued by McKoon and Ratcliff (1992), and hence are less susceptible to integrative priming. Nonetheless, the direction of this relationship between compound familiarity and integrative priming indicates that compound cueing cannot explain the occurrence of integrative priming. The compound cue model predicts greater priming among familiar compounds, but in Experiment 4, greater priming was found among unfamiliar compounds.

Conclusion

To conclude, we have shown across several experiments that relational integration facilitates lexical processing. Words are understood more quickly if they can be integrated easily with the preceding word. Moreover, the prevalence and magnitude of this integrative priming were on a par with associative priming and semantic priming. Given that relational integration is essential to and ubiquitous in language comprehension, this integrative priming is perhaps unsurprising. Perhaps more surprising is that this effect has been almost entirely overlooked for the past several decades of research on lexical priming. Integrative priming is not attributable to associative strength, semantic similarity, or compound familiarity. As such, it is not explicable via any extant model of lexical priming. We have argued that the mechanism of integrative priming will most likely be found within a role assignment model of relational integration, and we suspect that role typicality, relation plausibility, and compound familiarity will be important factors for determining whether integrative priming occurs prospectively and/or retrospectively. Clearly, much remains to be determined about integrative priming. The primary contribution of the present study has been to demonstrate its robust occurrence and its independence from other forms of lexical priming.

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Appendix A

Stimuli in Experiments 1, 2, and 3

	Prime		
Target	Integrative	Associative	Semantic
book*	travel	author	article
cake*	lemon	icing	muffin
can*	soup	opener	jug
candle	birthday	wick	flashlight
car*	race	tire	motorcycle
church*	town	priest	convent
diamond	necklace	gem	pearl
doctor*	horse	patient	sick
dog*	apartment	bone	fox
dress*	velvet	gown	lady
fish*	ocean	net	lobster
foot*	monkey	ankle	paw
garden	herb	hoe	lawn
ghost	halloween	ghoul	vampire
grape*	jelly	raisin	cherry
heart	donor	valentine	liver
horn	brass	bugle	clarinet
horse*	parade	mare	ox
house*	beach	mortgage	palace
idea	thesis	notion	insight
land*	border	acre	field
leaf	maple	rake	branch
lie	government	fib	fact
love	puppy	affection	trust
meat*	deer	butcher	vegetable
milk*	strawberry	calcium	juice
money*	copper	budget	credit
mouse*	farm	trap	chipmunk
pants*	linen	belt	blouse
paper*	rice	pen	envelope
piano*	concert	keyboard	harp
pipe*	steel	plumber	tube
plane*	corporate	pilot	rocket
rabbit	trick	carrot	mole
rain*	summer	umbrella	tornado
school	law	campus	office
sleep	airplane	nap	fatigue
snake*	jungle	cobra	crocodile
snow	mountain	ski	wind
soap*	bathroom	lather	shampoo
sport*	winter	athlete	tennis
teeth*	gold	dentist	tongue
toy*	plastic	yo-yo	game
wine*	box	cork	gin
wood	fireplace	termite	coal

Note. Asterisks denote items used in Experiment 3.

(*Appendixes continue*)

Appendix B

Stimuli in Experiment 4

	Prime	
Target	Integrative	Unrelated
beer	celebration	stairway
book	travel	pillow
car	company	celebration
cow	stable	winter
dance	square	company
doctor	horse	travel
dog	guide	square
fall	stairway	plastic
fence	chain	mushroom
fight	pillow	horse
flower	lapel	plug
food	pub	corporate
hat	plastic	glass
house	glass	guide
island	monkey	chain
light	plug	theory
math	theory	gold
money	copper	lapel
mouse	farm	lecture
paper	rice	beach
party	pool	farm
plane	corporate	stable
run	beach	box
sleep	lecture	monkey
smoke	industry	rice
soup	mushroom	pool
sport	winter	gear
stick	gear	pub
teeth	gold	industry
wine	box	copper

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