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Priming by relational integration in perceptual identification and Stroop colour naming.

Emily Mather[1,2], Lara L. Jones[3], & Zachary Estes[2,4]

[1]University of Hull, Department of Psychology, Cottingham Road, Hull, HU6 7RX, UK; email: emily.mather@hull.ac.uk; phone: +44 (0)1482 465403

[2]University of Warwick, Department of Psychology, Coventry CV4 7AL, UK

[3]Wayne State University, Department of Psychology, 5057 Woodward Ave., Detroit, MI 48202, USA

[4]BocconiUniversity, Department of Marketing, Via Rontgen 1, Milano 20136, ITALY

Abstract

Integrative priming is the facilitated recognition of a target word following a prime word with which it can be combined to produce a sub-type of the target (e.g., a lake bird is a type of bird). Such priming occurs even in the absence of lexical association, semantic similarity, or compound familiarity and so poses a challenge to current models of priming. The present research establishes integrative priming as a robust phenomenon across paradigms and tests whether it occurs controllably or uncontrollably. Target words (e.g., “bird”) were preceded by a prime word that was integratable (e.g., “lake”), associated and similar (e.g., “canary”), or unrelated (e.g., “trial”). Integrative priming was observed in a perceptual identification task that minimized strategic processing (Experiment 1) and in a Stroop colour naming task that penalized lexical integration (Experiment 2). Thus, like associative priming, integrative priming occurred uncontrollably. The results necessitate a distinct model of integrative priming, in which priming occurs automatically.

Keywords: associative priming; integrative priming; masked perceptual identification; relational integration; semantic priming; Stroop color naming.

Relational integration is a process of inferring a plausible relation (e.g., habitat) between two nouns (e.g., "lake" and "bird") to produce a compound meaning in which the first noun denotes a subtype of the second noun (e.g., a "lake bird" is a specific type of bird; Estes & Jones, 2006; Gagné & Shoben, 1997; Jones, Estes, & Marsh, 2008). Such relational integration is ubiquitous in language comprehension, with more than 80% of the noun pairs that occur in natural language being understood via relational integration (Gagné, 2000). Integrating words simply is how language is understood (Seidenberg et al., 1984), and indeed, some adult reading comprehension difficulties are related to an inability to integrate words (Perfetti, Yang, & Schmalhofer, 2008). It may come as no surprise, then, that relational integration facilitates word recognition (Estes & Jones, 2009; see also Badham, Estes, & Maylor, 2012; Jones & Golonka, 2012): A target word is recognised faster after a prime word with which it can be can be relationally integrated (e.g., monkey → foot) than after a neutral symbol (e.g., ***** → foot) or unrelated word (e.g., coin → foot). In fact, Estes and Jones (2009) demonstrated that such *integrative priming* effects were of the same general magnitude and prevalence as the associative and semantic priming effects. Unlike associative and semantic priming, however, integrative priming cannot be explained by any currently accepted mechanism of priming. As described below, all current mechanisms of priming operate via association, similarity, or co-occurrence (for reviews see Hutchison, 2003; Jones & Estes, 2012; McNamara, 2005), but integrative priming occurs among words that are unassociated, dissimilar, and do not frequently co-occur as a phrase. For example, "monkey" and "foot" rarely co-occur in language, they are not featurally similar, and they do not compose a familiar phrase. Yet, "monkey" speeds comprehension of "foot". So given that all current mechanisms of priming require association, similarity, or co-occurrence, and given that integrative priming occurs in the absence of those factors, a new mechanism is needed to explain integrative priming. The present research thus examines the nature of this mechanism of integrative priming.

Mechanisms of Lexical Priming

Mechanisms of priming may be partially distinguished by their underlying explanatory construct(s), which include association strength, similarity, familiarity, and co-occurrence (e.g., Jones & Golonka, 2012; Maki & Buchanan, 2008). *Association strength* is operationally defined as the proportion of a sample of people who produce a given target (e.g., night) in response to a particular cue (e.g., day) in a free association task, with "strong" association strength defined as at least 20% of the sample producing the given target (Hutchison, 2003). Association strength traditionally has been assessed using the University of South Florida Free Association norms (Nelson, McEvoy, & Schreiber, 1998, 2004), and recently more extensive association norms have been developed by asking participants to generate three associates per cue word rather than just their first response (De Deyne, Navarro, & Storms, 2013). *Similarity* refers to the degree of featural commonality shared by the prime and target. *Familiarity* refers to the subjective frequency of the combined prime and target (e.g., "dog house" would be more familiar than "rat house"). *Co-occurrence* refers to the extent that a prime and target occur together (but not necessarily as an adjacent pair) within a given text corpus.

Mechanisms of priming also vary on the extent to which they are controllable (i.e., strategic) or uncontrollable (i.e., automatic; see Jones & Estes, 2012; Jones, 2010). *Controlled* mechanisms operate strategically, or conditionally, according to processing constraints. For example, one can opt to compare "cat" and "mouse" or not, depending on one's current goals and task conditions. *Uncontrolled* mechanisms cannot be intentionally modulated. That is, "cat" and "mouse" are compared regardless of one's intention.[1] The controllability of a priming mechanism is often tested by manipulating the relatedness proportion (*RP*), which is the proportion of trials on which prime and target are related. The rationale is that conditions of high RP should promote strategic processing, because primes and targets are related on most trials and hence searching for a relation between prime and target would benefit responding. Conditions of low RP, in contrast, should discourage strategic processing, because searching for a relation between prime and target would rarely benefit responding. In general, if the given priming mechanism is under strategic control, then the priming effect should be larger when RP is high than when it is low. Alternatively, if the given priming mechanism is uncontrollable, then the priming effect should be just as large when RP is low as it is when RP is high (Hutchison, 2007; Hutchison et al., 2001).

However, there are several moderating factors in RP paradigms, such as the participant's working memory capacity and cognitive load, that also influence the reliance on controllable vs. uncontrollable processes (Hutchison 2007; Neely, O'Connor, & Calabrese, 2010; Perea & Rosa, 2002b). Proportions around .75 or .80 have typically been used for the "high RP" conditions with proportions of .25 or .20 for the "low RP" conditions (e.g., Hutchison et al., 2001; Neely, 1977; Perea & Rosa, 2002b). But strategic processing is still possible for these "low" RPs when sufficient attentional resources are available, such as when the delay between prime and target onsets (i.e., stimulus onset asynchrony, or "SOA") is greater than 300 ms or the inter-trial interval ("ITI") is greater than 400 ms (Neely, et al., 2010). In addition to a low RP, use of short SOAs or ITIs or a visual mask (e.g., Bodner & Masson, 2001, 2003; Grossi, 2006; Perea & Rosa, 2002b) can more conclusively demonstrate that priming is uncontrollable. For instance, masked priming typically entails both very short SOAs and a forward pattern mask prior to the brief prime presentation, thereby reducing (but not entirely eliminating) conscious awareness of the prime (Forster, 1998; Forster & Davis, 1984, 1991).

Current mechanisms of lexical priming are described below in terms of their underlying explanatory factors and their controllability.

Spreading Activation and Expectancy Generation**.** Spreading activation (Collins & Loftus, 1975) is based on strong associations between prime and target (e.g., day → night; Lorch, 1982; Perea & Rosa, 2002a, 2002b). Spreading activation occurs very rapidly following prime presentation, thereby pre-activating associated target words (Hutchison, Balota, Cortese, & Watson, 2008; Jones, 2013; Perea & Rosa, 2002a, 2002b; Yochim, Kender, Abeare, Gustafson, & Whitman, 2005). Activation can also spread indirectly from a prime to a target via a mediating concept that shares a strong association with both prime and target (Balota & Lorch, 1986; de Groot, 1983;

Jones, 2012; McNamara, 1992; McNamara & Altarriba, 1988). Association strength is also an important underlying factor of expectancy generation (Becker, 1980). Upon prime presentation (e.g., fruit), a set of potential targets is generated, with strongly associated concepts more likely to be included within that set (e.g., apple, orange, vegetables) than weak associates (e.g., tree; Estes & Jones, 2009; Jones, 2012; Jones & Estes, 2012; Thomas et al., 2012). The formation of an expectancy set takes approximately 300 ms to initially develop but longer to fully develop (Becker, 1980; Hutchison, Neely, & Johnson, 2001; Jones, 2012; Neely, 1977; Perea & Rosa, 2002a, 2002b). Although spreading activation and expectancy generation both operate via associations, these two mechanisms differ in their controllability. Whereas spreading activation is "automatic" or uncontrollable, expectancy generation is controlled (Hutchison et al., 2001; Neely, 1977; Neely et al., 1989; Thomas et al., 2012).

Distributed Representations. Semantic similarity (i.e., feature overlap) and/or co-occurrence are critical to distributed network models of semantic memory (Becker, Moscovitch, Behrmann, & Joordens, 1997; Lerner, Bentin, & Shriki, 2012; Masson, 1995; McRae & Boisvert, 1998; McRae, de Sa, & Seidenberg, 1997). Hearing or reading a prime word "automatically" activates its semantic features, which may be distributed across the semantic network. The representation of the target word will thus be more or less pre-activated, depending on its featural similarity to and/or co-occurrence with that prime word. Consequently, targets that have a high degree of featural overlap with the prime (e.g., cushion and pillow) or frequently co-occur with the prime (e.g., dog and leash) will be recognised faster than less similar targets (e.g., drapes and pillow; McRae & Boisvert, 1998) or infrequently co-occurring targets (e.g., dog and sweater; Lerner et al., 2012). This priming via activation of distributed representations is uncontrollable, and based on similarity or co-occurrence.

Semantic Matching. Semantic matching and other forms of post-lexical integration (Chwilla, Hagoort, & Brown, 1998; de Groot, 1985; Forster, 1979) entail a search for a meaningful relation between prime and target (Hutchison, 2007; Jones, 2010; Neely, 1977; Neely et al., 1989). In a lexical decision task, the participant is biased to respond that the target is a word if a semantic relation is present and to respond that it is a nonword if a relation is not present. The ease of finding such a relation is based on a backward association (Hutchison et al., 2008; Neely & Keefe, 1989) and/or similarity between prime and target (Estes & Jones, 2009; Perea & Rosa, 2002b), with some evidence of an associative boost for pairs that are both strongly associated and highly similar (Moss, Ostrin, Tyler, & Marslen-Wilson, 1995; for review see Hutchison, 2003; Lucas, 2000). Semantic matching is controllable, as shown by the presence of an RP effect (Estes & Jones, 2009; Hutchison, 2007) and by the fact that it is more likely to occur in experimental lists that contain a high nonword ratio (i.e., the probability of a target being a nonword, given that it is unrelated to the preceding prime; Neely et al., 1989).

Episodic Retrieval and Compound Cueing. Episodic retrieval occurs when the target word induces retrieval of the prime word, thereby affecting target responses (Bodner & Masson, 2001, 2003). Episodic retrieval of the prime may be based on either association or similarity to the target. Similarly, compound cue theory (McKoon & Ratcliff, 1992; Ratcliff & McKoon, 1988) posits that a prime and target are combined to form a compound cue. Priming is explained as the ease of retrieval of this compound cue from long-term memory, which in turn is based on the familiarity of the prime-target compound. McKoon and Ratcliff (1992) argued that the familiarity of a compound cue should be assessed by objective computational measures, such as frequency of co-occurrence in a massive text corpus, rather than by subjective perceptions of familiarity. Bodner and Masson (2001, 2003) found an RP effect on episodic retrieval, which at first may suggest controlled processing. Importantly though, their experiments used masked semantic primes presented briefly (45 ms), which diminished the possibility of controlled processes (Forster, 1998; Neely, et al., 2010; Perea & Rosa, 2002b). Thus, both episodic retrieval and compound cueing are assumed to be uncontrollable.

The Present Experiments

As described above, there are currently several hypothesized mechanisms of lexical priming. To be clear, these various mechanisms are not necessarily mutually exclusive; lexical priming may result from multiple processes (e.g., Jones, 2012; Neely & Keefe, 1989; Neely et al., 1989; Thomas et al., 2012). Indeed, the aim of the present research is not to test these extant mechanisms of priming, but rather to investigate a new mechanism that can explain integrative priming. To reiterate, integrative priming can occur among words that are unassociated, dissimilar, and unfamiliar as a phrase (Estes & Jones, 2009; Jones & Golonka, 2012). So given that current priming mechanisms work by association, similarity, or familiarity, integrative priming necessitates a new explanatory mechanism. The aim of the present experiments is to further establish the phenomenon of integrative priming and examine whether it occurs controllably or uncontrollably.

Manipulations of RP have no effect on integrative priming (Estes & Jones, 2009). This suggests that integrative priming is beyond strategic control; if it were controllable, then participants should not have attempted to integrate when few primes and targets are related. However, this result is not conclusive: Although such low RP conditions render controlled processing unlikely, a strategy of integrating primes and targets would nonetheless speed responses on those trials where integration was possible. Given the relatively long SOA (500 ms) and ITI (1000 ms) and the lack of a visual mask used in Estes and Jones's RP experiments, such a strategy may have been possible even in their "low" (.20) RP condition. Thus it remains unclear whether integrative priming occurs controllably.

To provide a more stringent test of whether integrative priming is controllable, Experiment 1 used a perceptual identification task because priming in this task is generally considered to result from automatic processing (Pecher, Zeelenberg, & Raaijmakers, 2002; see also Neely & Keefe, 1989). For instance, in a perceptual identification task with visual masking, brief presentation of primes and targets (about 42 ms), and an SOA of 0 ms, Pecher et al. (2002, Experiment 2A) found no RP effect and significant associative priming within both their high (.90) and low (.10) RP conditions. Thus, the observation of integrative priming in this task would indicate uncontrollability. In Experiment 1, integrative priming was examined by comparing responses to a target word following either a prime word with which it is easily integrated (e.g., horse → doctor) or a prime word that is completely unrelated and difficult to integrate (e.g., sphere → doctor). Critically, the target word was flashed only very briefly (20 ms), followed by a visual mask, and participants' task was simply to report the target word if they could. Integrative priming would be observed as more accurate identification of the target after an integrative prime than after an unrelated prime. The brief, masked presentation of the target word was intended to limit participants' conscious awareness, so that participants could not intentionally control their lexical processing of the target (Pecher et al., 2002). As a further constraint against controllable processing, we used integrative primes and targets that were unassociated, dissimilar, and low in co-occurrence. This rendered it highly unlikely that participants could strategically use the prime word to guess the identity of the target word (e.g., via expectancy generation). Finally, for comparison, Experiment 1 also included primes and targets that are associatively related (e.g., nurse → doctor), because associative priming has been observed in this task (Pecher et al., 2002). Thus, each target was preceded by one of three prime-types (i.e., unrelated, integrative, associative).

To provide an additional novel test of whether integrative priming is controllable, Experiment 2 used the Stroop colour naming task. Target words that were unrelated, easily integrated, or associated with their primes were presented in one of three colours, and participants named aloud the colour of font in which the target word appeared. We used the colour naming task because lexical integration would actually *hinder* responding, so if it were controllable, then integration should be avoided and hence integrative priming should not occur (Burt, 1999).[2] To illustrate, associative priming is generally believed to be uncontrollable (Hutchison, 2003; Pecher et al., 2002; Perea & Rosa, 2002a); it speeds lexical decisions and word naming but hinders colour naming (Burt, 1999). Because associative priming facilitates recognition of the target word, that target competes with and slows naming of the colour word. Suppose the target "doctor" appears in blue font after the associative prime "nurse". Because "nurse" facilitates recognition of "doctor", both the target "doctor" and the colour word "blue" are strongly activated, and the competition between these words delays the correct response ("blue"). Thus, relative to unrelated primes, associative primes hinder colour naming. If integrative priming is also uncontrollable, then it should also exhibit interference in this task.

Experiment 1: Perceptual Identification

Experiment 1 followed standard procedures for priming studies of masked perceptual identification (Masson & MacLeod, 1992). Because this task measures uncontrollable processing (Pecher et al., 2002), and because associative priming occurs uncontrollably (Balota et al., 2008; Jones, 2010, 2012; Thomas et al., 2012), target words should be identified more accurately after associative primes than after unrelated primes. If integrative priming also occurs uncontrollably, then target identification should be more accurate after integrative than unrelated primes.

Method

Participants. Participants in both experiments were students or employees at the University of Warwick, recruited via campus and website advertisements. All spoke English as their first language, had normal or corrected vision, and received £3 for participation. None participated in both experiments. In Experiment 1, 33 participants (16 male, 17 female) had a mean age of 24 years (*range* = 18-56). Four additional participants were excluded from analysis for reporting English as a non-native language (2) or failing to follow instructions (2).

Stimuli. Each of 45 target nouns was paired with an associative, integrative, and unrelated prime (see Appendix A). In addition to these 135 noun pairs, a further ten unrelated noun pairs were presented during practise trials. The experimental stimuli were selected from a larger set of 64 targets used in another study (Jones, 2013) on the basis of associative strength, co-occurrence, integratability, and semantic similarity[3]. Values for forward (prime → target) and backward (target → prime) association strength were originally obtained from Nelson, McEvoy, and Schreiber (1998, 2004). Subsequent to the conduct of this study, however, De Deyne et al. (2013) created an alternative set of association strengths that required participants to provide three associates to each cue word rather than just one. We therefore additionally calculated forward and backward association strengths for our stimuli using De Deyne et al.'s new norms (see Table 1). Fortunately, 91% of our 180 stimulus words (135 primes + 45 targets) were present as cue words in the De Deyne et al. norms. For each cue word we calculated the proportion of participants whose response set included the target word, regardless of the target's rank among that response set (i.e., first, second, or third associate listed).

Separate groups of undergraduates at Wayne State University rated the similarity (*N* = 30) and integratability (*N* = 20) of all 135 prime-target pairs. Similarity was rated on a scale from 1 (not at all similar) to 7 (very similar). Integratability was rated as the extent to which each prime-target pair could be linked together to form a sensible phrase on a scale from 1 (not linked) to 7 (tightly linked; cf. Estes & Jones, 2009). Global co-occurrence was measured via LSA cosines (latent semantic analysis; Landauer & Dumais, 1997), which quantify the similarity of the texts in which the two words occur, and also via the number of hits to the prime-target pair in the UK site of internet search engine Google (search term: [prime] [target]; date of retrieval: 31 January 2013), which represents the number of webpages that include both the prime and target words (though not necessary adjacently, and regardless of word order). Local co-occurrence was measured via Beagle cosines (Jones & Mewhort, 2007), and also as the number of hits to the prime-target pair in Google UK (search term: "[prime] [target]"; date of retrieval: 31 January 2013). The inclusion of quotation marks around the prime-target pair returns the number of webpages that include the prime and target as an adjacent pair, preserving the order of the words. This measure of local co-occurrence is known to predict lexical priming (Estes & Jones, 2009; Jones & Golonka, 2012) and semantic processing more generally (Griffiths, Steyvers, & Firl, 2007). Finally, we also created measures of global and local predictability as the conditional probability of the target occurring, given the prime. We again used Google UK to obtain hits (date of retrieval: 31 January 2013), with quotations for the local predictability measure and without quotations for global predictability.

Similarity and integration ratings were normally distributed (skew = .56 and .49 respectively), as were Beagle cosines (.81). Association values were positively skewed in both the Nelson norms (forward = 1.36, backward = 4.48) and the De Deyne norms (forward = 1.37, backward = 4.52), given the prevalence of zero values in the integrative and unrelated conditions. Because log transformations did not substantially improve the skew, raw association values were used in analyses. LSA cosines (1.03) and all four Google measures (global and local co-occurrence and predictability) were also skewed (all > 3.39), but log transformation substantially reduced this skew (all < .74). Transformations used the natural logarithm, with a constant of 1 added to all predictability scores prior to transformation to avoid the problem of numbers less than 1. Analyses therefore used these transformed LSA and Google values, but note that raw (untransformed) predictability measures are reported in Table 1 to facilitate comprehension.

Integrative pairs were selected to be high on integratability, but low on association, similarity, and co-occurrence. Associative pairs were selected to be highly associated and similar but low on integratability, and unrelated pairs were selected to be low on all values (see Table 1). The associative condition was significantly higher than the integrative condition in both forward association (both Nelson and De Deyne values, $p < .001$) and similarity, $t(70) = 13.0$, $p < .001$. The mean integratability rating for the integrative condition was significantly higher than the associative condition, $t(83) = 4.51$, $p < .001$, and the unrelated condition, $t(53) = 14.7$, $p < .001$.[4]

Design. Each participant was presented with 10 practice trials followed by 135 experimental trials. The experiment had a prime (*integrative*, *associative*, *unrelated*) × block (*1*, *2*, *3*) repeated-measures design. Trials were divided into three blocks of 45 trials. Each of the 135 pairs was presented once during the experiment, and every target word appeared once per block, with the constraint that every block contained 15 pairs from each of the associative, integrative, and unrelated conditions. For each participant, the sequence of blocks and trials within a block were randomized. The sequence of practise trials was also randomized.

Procedure. Participants were individually tested in a sound-attenuated cubicle using E-Prime 2.0 to deliver trials and record vocal responses, which were recorded via an adjustable microphone positioned close to the participant's mouth. Participants viewed an instruction screen explaining the following: "*...During each trial, you will briefly see a word in black followed by another word in* *blue that will be hidden by a row of hash symbols (i.e., ##########). After you've seen the *hidden* blue word, please say out loud into the microphone the blue word that you saw. If you are unsure about the word, please just give us your best guess…"*. All primes, targets, and masks were displayed in 18pt Courier New font and centrally positioned on screen. As shown in Figure 1, each trial consisted of a prime word displayed in black font for 100 ms, followed by an interstimulus interval of 400 ms, and subsequently the presentation of the target word in blue font for 20 ms. Immediately following the offset of the target word, a row of 8 hash symbols in blue was presented for 67 ms, serving as a perceptual mask. Participants had up to 3 s to say aloud the target word, during which time the visual display was blank. Following this fixed response period, a prompt was displayed ("ready?") to indicate that the participant could proceed onto the next trial by pressing the space bar. The experimental session lasted approximately 15 minutes.

Data coding. Participants' accuracy in identifying the target words was determined by auditory replay of each vocal response after completion of the experiment.

Results and Discussion

Data were analysed via mixed effects regression with participants and items as crossed random effects (Baayen, Davidson, & Bates, 2008). Given the categorical nature of the dependent measure (i.e., each trial was correct or incorrect), data were analysed via binary logistic regression, which is based on the Wald χ^2 statistic (Field, 2009). An overall model with prime (associative, integrative, unrelated), block (1, 2, 3), and their interaction as fixed factors was highly significant, $\chi^2(8) = 228.41$, $p < .001$. Moreover, the analysis revealed significant effects of prime, Wald $\chi^2(2) = 49.53$, $p < .001$, and block, Wald $\chi^2(2) = 19.70$, $p < .001$, without interaction ($p = .93$). Accuracy increased across blocks 1 (M = 67%, SE = 1%), 2 (M = 73%, SE = 1%), and 3 (M = 77%, SE = 1%). This effect of block constitutes repetition priming, as the targets appeared once per block. However, the lack of interaction between block and prime suggests that the priming effect was relatively constant across these repetitions. Accuracy was significantly higher in the associative condition (M = 82%, SE = 1%) than in the integrative condition (M = 75%, SE = 1%), Wald $\chi^2(1) = 6.17$, $p < .05$, and the unrelated condition (*M* = 60%, *SE* = 1%), Wald $\chi^2(1) = 45.60$, $p < .001$. The advantage of associative over unrelated primes constitutes associative priming in the perceptual identification task, thereby replicating prior research (Pecher et al., 2002) and validating the present methods and samples. Most critically for the present purposes, accuracy was also significantly higher in the integrative condition than in the unrelated condition, Wald $\chi^2(1) = 19.96$, $p < .001$. This result suggests significant integrative priming in perceptual identification.

Note, however, that these initial analyses do not include the control variables listed in Table 1. In order to demonstrate integrative priming more convincingly, we conducted further analyses to examine whether integrative priming was related to association strength, similarity, or co-occurrence, and whether the integrative priming effect remained significant when those covariates were statistically controlled. We first tested for collinearity among our five original control variables of forward association (Nelson et al., 2004), backward association (Nelson et al., 2004), similarity, global co-occurrence (LSA), and local co-occurrence (Google hits). There was no problem of collinearity (all tolerance > .38 and VIF < 2.59), indicating that the five control factors were sufficiently independent for inclusion in the same analysis (Field, 2009).

Before analyzing the impact of these control factors on integrative priming, we sought to validate our measures and analyses by conducting further analyses of associative priming: If the control measures significantly predict identification accuracy, and their inclusion substantially improves the fit of the model, this would provide positive evidence that our measures and analyses are valid. We therefore conducted a binary logistic mixed effects regression that included all five control variables, and as expected, forward association, backward association, similarity, and local co-occurrence all significantly predicted identification accuracy. However, because global co-occurrence did not predict accuracy, it was removed from further analyses. A subsequent regression with prime (associative vs. unrelated), block, the prime*block interaction, and the four remaining control factors was highly significant, $\chi^2(9) = 269.60$, $p < .001$. The analysis confirmed the significant effects of forward association ($\beta = 1.91$, $SE = .59$, $p < .001$), backward association (β = -

5.48, *SE* = 2.36, $p < .05$), similarity ($\beta = .29$, *SE* = .06, $p < .001$), and local co-occurrence ($\beta = .07$, *SE* = .03, $p < .05$). That is, perceptual identification was more accurate after prime words that had strong forward associations and weak backward associations, and after prime words that were similar to and co-occurred often with the target word. Critically, the observation that the factors previously shown to predict associative priming also predicted associative priming in the current experiment serves to validate this set of control factors. Moreover, we examined the collective contribution of these control factors to associative priming, in terms of model fit, by comparing effect sizes of the overall model in separate regressions with and without the control factors. In logistic regression, effect size is estimated by the likelihood ratio (specifically, -2 log likelihood). When no control factors were included in the regression, the likelihood ratio was 3350. When the four significant control factors were added, however, the likelihood ratio decreased to 3290. The magnitude of this difference (i.e., 60) indicates that, as expected, forward association, backward association, similarity and local co-occurrence substantially improved the fit of the model. This provides further validation of our control measures and our statistical methods.

The question of greater interest here is whether significant integrative priming occurred, after accounting for the control factors listed in Table 1, which we tested by comparing directly the integrative and unrelated conditions (i.e., excluding the associative condition). We conducted a logistic mixed effects regression that included all five control variables, but because local co-occurrence (Google hits) was the only control variable that significantly predicted accuracy, all other control variables (all $p > .13$) were excluded from further analysis. A subsequent regression with prime (integrative vs. unrelated), block, the prime*block interaction, and local hits confirmed the significant effect of local hits, $\beta = .06$, *SE* = .02, $p < .01$. Targets were identified more accurately after primes with which they occur more frequently. This result corroborates that of Jones and Golonka (2012, Experiment 4), who found that local co-occurrence reliably predicted faster target RTs following integrative primes. Despite this effect of local co-occurrence, however, the effect of prime was also significant, $\beta = .43$, *SE* = .16, $p < .01$: Accuracy was significantly higher in the integrative condition than in the unrelated condition. The effect of block was also significant, $\beta = .58$, $SE = .13$, $p < .001$, with accuracy increasing across blocks as described above. The interaction did not approach significance ($p = .90$). We also tested an additional model that included the prime*local hits interaction, but this interaction term was nonsignificant ($p = .56$). Finally, we also examined the contribution of the control factors to integrative priming in the same way that we did for associative priming, by comparing model fits with and without the significant control factors. When no control factors were included in the model, the likelihood ratio was 3636. When the significant control factors were added (i.e., local co-occurrence), however, the likelihood ratio decreased only slightly to 3627. Notably, the magnitude of this difference (i.e., 9) was much smaller than that observed in associative priming (i.e., 60; see above). Relative to associative priming then, this small effect size indicates that inclusion of control factors did not substantially improve the fit of the model. These analyses thus reveal significant integrative priming even after accounting for the effect of word pair frequency (i.e., local co-occurrence), which was significant but small.

The preceding analyses tested for integrative priming after accounting for the five control variables that we originally intended. However, a number of alternative measures are also available (see Table 1). Thus, to provide a more conservative test of integrative priming, we conducted an additional analysis in which the best available predictors were included. That is, for each construct (e.g., local co-occurrence), we examined which measure of that construct (e.g., Beagle, hits, predictability) correlated most strongly with the dependent variable (perceptual identification accuracy), and we selected that measure for inclusion in a new regression model. The best predictors were Nelson forward association ($r = .46$, $p < .001$), De Deyne backward association ($r = .23$, $p < .01$), similarity ($r = .57$, $p < .001$), LSA global co-occurrence ($r = .43$, $p < .001$), and local hits ($r = .45$, $p < .001$). The five predictors were non-collinear (all tolerance > .36 and VIF < 2.75). A logistic mixed effects regression with these best five control factors once again revealed that local hits was the only control factor that significantly predicted accuracy (all other control factors $p >$

.09), so the results remained the same as reported in the preceding analysis: Even after selecting and accounting for the best of our various control factors, integrative priming remained significant. We also conducted additional regressions including various combinations of the different control factors, and each time the effects of prime and block were significant without interaction. Integrative priming appears to be a robust phenomenon that is not attributable to semantic association, similarity, or co-occurrence. In sum, Experiment 1 demonstrated reliable integrative priming in the perceptual identification task, providing a robust 15% increase in accuracy. Because this task measures automatic processing (Pecher et al., 2002), integrative priming appears to occur uncontrollably.

Experiment 2: Colour Naming

To further test whether integrative priming is controllable or uncontrollable, Experiment 2 followed standard procedures for priming studies of Stroop colour naming (cf. Burt, 1999). Critically though, our procedure maximised the possibility that lexical priming would hinder rather than facilitate colour naming: A long delay between prime and target onset (1750 ms) and a requirement to read aloud the prime word are highly conducive of interference in colour naming (Burt, 1999, 2002). Thus, our task discouraged lexical priming; if participants were able to strategically avoid priming, they would perform optimally in this task. But because associative priming occurs uncontrollably (Pecher et al., 2002), target words should elicit slower colour naming after associative primes than after unrelated primes (Burt, 1999). If integrative priming also occurs uncontrollably, then targets should also elicit slower colour naming after integrative than unrelated primes. Alternatively, if integrative priming is controllable, then colour naming should be equally fast after integrative and unrelated primes. Of course, our participants have many years’ experience integrating words during language use, and such integration has surely proven useful. So even if integrative priming is controllable, some number of trials might be required before this strategy of lexical integration is abandoned. Such a gradual process of learning and adapting to the current task would be evident as a difference between the integrative and unrelated conditions that decreases across blocks. We therefore would consider either a null difference between the integrative and unrelated conditions or an interaction between prime and block as evidence that integrative priming is controllable.

Note that this test of controllability cannot discriminate between conscious-intentional control and unconscious-unintentional control. That is, a null effect of prime or a prime × block interaction would be predicted regardless of whether participants consciously perceive the presumed interference from integrative priming and intentionally abandon the integrative strategy, or whether they adapt their processing unconsciously. Likewise, if interference from integrative priming were observed to be constant across blocks, such a result could not determine whether participants were consciously aware that lexical integration was hindering their performance. Thus, the present experiment makes no assumptions and provides no conclusions about whether integrative priming occurs consciously or unconsciously. Rather, the present experiment simply tests whether integrative priming is controllable or uncontrollable.

Method

Participants. Thirty-two participants (17 male, 15 female) had a mean age of 21 years (*range* = 18-27). Four additional participants were excluded from analysis for failing to follow instructions (3) and a disruption to the testing session (1).

Stimuli. Stimuli were the same as in Experiment 1.

Design. The design was the same as Experiment 1, except that the colour of the target word (blue, green, red) was counterbalanced across blocks for each target, and each colour appeared approximately equally often within each prime condition within each block. Nine unrelated noun pairs were presented during practise trials.

Procedure. The experiment was administered using the same equipment and software as Experiment 1. Participants were instructed as follows: "*...During each trial, you will first see a word in black font, followed by another word in one of three font colours: RED, BLUE, GREEN. YOUR TASK: 1) Read out loud the first word 2) Say out loud the COLOUR of the second word.*

REMEMBER: Do NOT read out the second word, just say what colour it is. Please say the first word and second word colour as quickly as possible..." All primes and targets were presented in 18pt Courier New font and centrally positioned on screen. During each trial, a prime was presented in black font for 1500 ms, followed by an interstimulus interval of 250 ms, so that participants had 1750 ms in which to read aloud the prime (see Figure 2). The target then appeared for 2000 ms in blue, green, or red font. Following the offset of the target word, the visual display was blank for 500 ms, providing participants with 2500 ms to name the colour of the target. Finally, a prompt ("ready?") indicated that the participant could proceed onto the next trial by pressing the space bar.

Data coding. Both prime and target responses were coded for accuracy, but only target responses were coded for latency. For primes, responses were considered incorrect if the participant uttered a different word or substantially mispronounced the prime. Responses were also classified as incorrect if the utterance was truncated by the offset of audio recording. For targets, errors were classified as one of the following: utterance of the target word, utterance of the wrong colour, silent or incomplete utterance, and extraneous sounds preceding the target response. A script written in Goldwave was used to identify the approximate onset of target words, with a coder listening and manually adjusting the onset marker as required.

Results and Discussion

Prime accuracy. The average error rate across participants was 3.4% (range = 0-10.4%). Logistic mixed effects regression with participants and items as crossed random effects and prime-type as a fixed effect confirmed that these rare errors were distributed uniformly across the associative, integrative, and unrelated conditions (p = .53). All trials containing prime response errors were excluded from analyses of target accuracy and latency. Because the prime "lapel" elicited errors (typically mispronunciation due to its irregularity: LA-pel) by 59% of participants, we also excluded this item ("lapel" → "flower") from all analyses.

Target accuracy. The average target error rate was only 1.7% (range = 0-6.7%). The majority of these rare errors entailed utterance of the target word or an incorrect colour. Logistic mixed effects regression found no significant difference in accuracy across the associative, integrative, and unrelated conditions ($p > .07$). All trials containing target response errors were excluded from analyses of target latency.

Target latency. Outliers greater than 2.5 *SD*s from the participant's condition mean were excluded (1.8% of trials). Data were analysed via linear mixed effects regression with participants and items as crossed random effects (Baayen et al., 2008). An overall model with prime (associative, integrative, unrelated) and block (1, 2, 3) as fixed factors revealed significant effects of prime, $F(2, 3957) = 5.66$, $p < .01$, and block, $F(2, 3935) = 26.62$, $p < .001$, without interaction ($p = .29$). The effect of block was manifest as response times (in ms) that slowed across blocks 1 ($M = 746$, $SE = 5$), 2 ($M = 765$, $SE = 5$), and 3 ($M = 788$, $SE = 6$), as is common with colour naming of repeated target words (McKenna & Sharma, 1995). However, the lack of interaction between block and prime suggests that the priming effect was relatively constant across these repetitions and is consistent with past findings showing the additive rather than interactive effects of word repetition and prime-type (den Heyer, Goring, & Dannenbring, 1985). Collapsed across blocks, colour naming was significantly slower in the associative condition ($M = 774$, $SE = 5$) than in the unrelated condition ($M = 757$, $SE = 5$), $t(2622) = 3.42$, $p < .001$. This difference replicates prior demonstrations of associative priming in the Stroop task (Burt, 1999), thereby validating the present methods and samples. The associative condition did not differ significantly from the integrative condition ($M = 768$, $SE = 5$), $p = .23$. Most critically for the present purposes, however, colour naming was significantly slower in the integrative condition than in the unrelated condition, $t(2648) = 2.04$, $p < .05$.

As in Experiment 1, we sought to validate our control measures and analyses by first examining their effects on associative priming. A preliminary analysis compared the associative and unrelated conditions and included all five of our original control variables: Nelson forward and backward association, similarity, global co-occurrence measured as LSA cosines, and local co-occurrence measures as Google hits (all tolerance > .37 and VIF < 2.69). Backward association was the only control factor that significantly predicted RT, $\beta = .30$, $SE = .15$, $p < .05$, whereas accuracy in the perceptual identification task of Experiment 1 was additionally predicted by forward association, similarity, and local co-occurrence. Thus, associative priming may be supported by different factors in the different paradigms. In particular, the additional contributions of forward association, similarity and local co-occurrence supports the assumption that perceptual identification relies primarily on uncontrolled processing (Pecher et al., 2002), as those factors are generally thought to indicate processing without intention. Following the methods of Experiment 1, we also examined the contribution of the control factors to associative priming, in terms of model fit, by comparing likelihood ratios of the overall model in separate regressions with and without the control factors. When no control factors were included in the regression, the likelihood ratio was -2825. When the significant control factors were added (i.e., backward association), the likelihood ratio changed only minimally to -2826. The small magnitude of this difference indicates that although backward association significantly predicted RTs in associative priming, this contribution did not substantially improve the fit of the model.

Finally, to test for integrative priming, a preliminary analysis compared the integrative and unrelated conditions and included all five of the original control variables. None of these control variables significantly predicted latencies (all $p > .11$), so they were excluded from further analysis. A subsequent regression with prime, block, and the prime*block interaction yielded a significant effect of prime, $F(1, 2644) = 4.13$, $p < .05$: Colour naming was significantly slower after an integrative prime than after an unrelated prime. The effect of block was also significant, $F(2, 2644) = 14.30$, $p < .001$, with slower latencies across blocks as described above. The interaction was not significant ($p = .28$). The likelihood ratio, indicating the overall model fit, was -2887. This model fit was comparable to that for associative priming (see above). To provide a more conservative test of integrative priming, as in Experiment 1, we also sought to conduct an additional analysis in which the best available predictors were included. The best predictors of target latencies were Nelson forward association ($r = .17$, $p = .06$), Nelson backward association ($r = .28$, $p < .001$), similarity (r

= .21, $p < .05$), LSA global co-occurrence ($r = .19$, $p < .05$), and Google hits as local co-occurrence ($r = .14$, $p = .11$). That is, our five original control factors were in fact the five best predictors of colour naming latencies, so this analysis would be entirely redundant with that reported above. We did nonetheless conduct additional regressions including various combinations of the different control factors (e.g., replacing the Nelson association values with the De Deyne association values), but each time the control factors failed to predict colour naming latencies. Thus, the significant integrative priming was not attributable to semantic association, similarity, or co-occurrence. In sum, associative and integrative primes both interfered with target colour naming. Because this task measured priming that is uncontrollable (Burt, 1999, 2002), these results indicate that integrative priming, like associative priming, occurs uncontrollably.

General Discussion

Integrative priming was observed in a perceptual identification task that reduced controllable processes (Experiment 1) and in a colour naming task that penalized lexical integration (Experiment 2), thereby suggesting an uncontrollable process. Prior experiments demonstrated integrative priming in lexical decisions (Badham et al., 2012; Estes & Jones, 2009; Jones & Golonka, 2012), but the LDT paradigms used in those studies were susceptible to both controllable and uncontrollable processing. The perceptual identification task of Experiment 1, in contrast, is less subject to controlled processing (Pecher et al., 2002; see also Neely & Keefe, 1989). With near-subliminal target presentation (20 ms) followed immediately by a visual mask, the target word was severely degraded, with 60% accuracy in the control condition. However, an integrative prime increased target accuracy to 75%. Experiment 1 thus suggested that integrative priming occurs uncontrollably. Furthermore, the finding of integrative priming—in the form of interference—in the Stroop colour naming task (Experiment 2) strengthens this conclusion that the integration of prime and target words was beyond participants' strategic control. So then the present study demonstrates that integrative priming entails a unique form of uncontrolled processing that is distinct from the uncontrollable mechanisms underlying prior accounts of associative and semantic priming, which were based on having sufficient association strength, similarity and/or co-occurrence.

Given that integrative priming has been identified only quite recently (Estes & Jones, 2009) relative to the better known associative and semantic priming effects (e.g., Meyer & Schvaneveldt, 1971), it bears consideration whether integrative priming is truly distinct from associative and semantic priming. Our approach was fourfold: (1) We sampled integrative word pairs that were low in association strength, featural similarity, and lexical co-occurrence, (2) we used multiple measures of association strength (De Deyne et al., 2013; Nelson et al., 1998, 2004) and lexical co-occurrence (LSA cosines, Beagle cosines, and Google-based measures of global and local hits and predictability), (3) we tested whether these lexical control factors predicted our critical dependent measures, and if so, then (4) we included them as predictors in our main analyses of integrative priming. Association strength among the integrative pairs was non-zero but extremely low by both measures, and neither measure significantly predicted performance in either experiment. Semantic similarity was also low among the integrative pairs, and it also failed to predict performance in either experiment. Some measures of lexical co-occurrence were notably higher among the integrative pairs than among the unrelated pairs, and indeed one measure of co-occurrence (namely, the local Google hits) significantly predicted performance in the perceptual identification task (but not the colour naming task). However, even after statistically accounting for the effect of co-occurrence in perceptual identification, the integrative priming effect remained significant and stable across blocks. More generally, we sought to be as thorough and systematic as possible in controlling our integrative stimuli and statistically accounting for other stimulus characteristics. We used measures that are the standard in the field (e.g., the Nelson et al. free association norms; LSA cosines), supplemented with additional measures that are less established but potentially more powerful (e.g., the De Deyne et al. free association norms; Google hits), and we used mixed effects modelling to maximise the statistical power of our analyses. Thus, integrative priming does not appear to be explicable in terms of association, similarity, or co-occurrence. That is, integrative priming appears to be empirically distinct from associative priming and semantic priming.

In the present study, integrative priming elicited a significantly smaller effect than associative priming in the perceptual identification task but not in the colour naming task. In terms of prevalence, Estes and Jones (2009) found that 67% of their participants exhibited integrative priming (i.e., faster mean RT after integrative primes than after control primes), 66% exhibited semantic priming, and 81% exhibited associative priming in the lexical decision task. In the perceptual identification task of the present study, 97% exhibited associative priming and 91% exhibited integrative priming. In the colour naming task of the present study, 69% displayed associative priming and 63% displayed integrative priming. Moreover, Estes and Jones obtained significant integrative priming effects across a broad range of prime-target delays (SOAs ranging from 100 to 2500 ms) and across various experimental contexts (RPs ranging from .20 to .80). Integrative priming thus appears about as robust as associative and semantic priming.

These results are not explicable by current priming mechanisms that operate under strategic control (e.g., expectancy generation, semantic matching). On one hand then, these results may appear consistent with several extant mechanisms that act uncontrollably (i.e., spreading activation, activation of distributed representations, episodic retrieval, and compound cue models). But importantly, those models attribute priming to association, similarity, or co-occurrence (Jones & Estes, 2012; Thomas et al., 2012), whereas integrative priming occurs among words that are unassociated and dissimilar and that co-occur rarely. These results therefore suggest that another mechanism must be at work in integrative priming.

Complementary Role Activation. How might integrative priming occur uncontrollably in the absence of association, similarity, or co-occurrence? We propose that integrative priming results from the automatic activation of complementary roles (see also Maguire, Maguire, & Cater, 2010; Wisniewski, 1997). For instance, “lake” automatically activates a set of semantic features (Becker et al., 1997; Lerner et al., 2012; Masson, 1995; McRae & Boisvert, 1998; McRae et al., 1997) and associated concepts (Collins & Loftus, 1975; Hutchison et al., 2008; Jones, 2013; Perea & Rosa, 2002a, 2002b; Yochim et al., 2005) that collectively identify it as a *habitat*. Likewise, "bird" activates a set of features and associations that identify it as an *animal*. Because these *habitat* and *animal* roles complement one another in a *habitation* relation, the search for a plausible relation between prime and target is terminated quickly and hence comprehension is facilitated (cf. Maguire et al., 2010). Similarly, to understand "plastic hat" one must identify "plastic" as a *substance* and "hat" as an *object*, and because those relational roles are complementary, comprehension is facilitated. If a plausible relation integrating the prime and target is difficult or impossible to resolve, then comprehension will be accordingly delayed or prevented. Integrative priming thus can be explained by complementary role activation: The prime and target words activate their typical relational roles, and if the activated roles can plausibly complement one another to instantiate a specific relation, then recognition is facilitated. The speed with which such complementary roles are identified determines the magnitude of integrative priming. Moreover, the uncontrollability of this hypothesized mechanism follows from much prior research: It is well established that activation of semantic features and associated concepts occurs automatically upon word presentation (Becker et al., 1997; Collins & Loftus, 1975; Hutchison et al., 2008; Jones, 2013; Lerner et al., 2012; Masson, 1995; McRae & Boisvert, 1998; McRae et al., 1997; Perea & Rosa, 2002a, 2002b; Yochim et al., 2005), so to the extent that those semantic features and associated concepts are sufficient to identify a word's relational role(s), role activation would also occur automatically.

This hypothesis of lexical priming via complementary role activation is supported by its ability to explain another related phenomenon, namely, *relation priming*: Relational integration of a target word pair (e.g., "straw hat") is faster after another word pair that entails the same relation (e.g., "steel scissors") than after another word pair that entails a different relation (e.g., "steel factory"; Estes, 2003; Estes & Jones, 2008; Spellman, Holyoak, & Morrison, 2001; Wisniewski & Love, 1998; see also Raffray, Pickering, & Branigan, 2007 for a demonstration with pictorial stimuli). Relation priming even occurs among word pairs that are lexically dissimilar but relationally similar (Estes & Jones, 2006). The critical determinant of relation priming appears to be whether the prime and target word pairs are understand by the same relation (or relational roles). Complementary role activation thus naturally and simply explains relation priming as the prime combination (e.g., "swamp rat") pre-activating the relational roles (e.g., *habitat*, *inhabitant*) that are necessary to integrate the target combination (e.g., "lake bird"). This ability of complementary role activation to explain both established phenomena (i.e., relation priming) and novel phenomena (i.e., integrative priming) lends it not only plausibility, but also broader explanatory power.

In fact, this hypothesis of complementary role activation provides a novel prediction: The degree of semantic constraint that an activated role or role-filler provides should predict the magnitude of integrative priming. Some relational roles are more constraining than others, and these differences in semantic constraint may speed or slow the judgment of whether the target complements the prime (see also Maguire et al., 2010). This prediction can be tested by examining whether integrative priming is asymmetric. For example, prime words that perform an *occupation* role (e.g., "plumber") facilitate semantic decisions to target words that perform an *instrument* role (e.g., "wrench"). In contrast, no priming is observed when these words are presented in the reverse direction (e.g., wrench → plumber), presumably because the *instrument* role for the prime word "wrench" is less semantically constraining than the *occupation* role for the prime word "plumber" (i.e., anyone can use a wrench, but plumbers typically use only certain tools; Hare, Jones, Thomson, Kelly, & McRae, 2009). Such asymmetric effects of relational integration have also been demonstrated in recognition memory performance (Jones, Estes, & Marsh, 2008). Similarly, some role-fillers are more constraining than others, and this might also affect the magnitude of integrative priming. For the *material* role, some primes (e.g., straw) would be more constraining than others (e.g., plastic) due to their physical properties (i.e., just about anything can be made of plastic, whereas straw is only suitable for soft things). More highly constraining role-fillers (e.g., "straw") should facilitate the determination of whether an adjacent word (e.g., "hat") can plausibly complement it, thereby speeding recognition. For example, "straw" is strongly associated with the *material* role, which in turn is strongly associated with the complementary *object* role, and the "straw" material also semantically constrains the set of *object* concepts that could plausibly complement it, thus producing robust priming effects for those complementary targets (e.g., straw → hat). However, in the reverse (and less integratable) direction (e.g., hat → straw; straw that is to be used for making hats), integrative priming is not likely to obtain because the rather generic *object* role for "hat" is less semantically constraining (Recchia & Jones, 2012; see also Hare et al., 2009). Thus, we believe that the degree of constraint provided by specific roles and fillers is an important area for future studies of integrative priming.

Another issue that the present research did not address, but which will likely be important for future studies, is the directional nature of integrative priming. That is, priming may occur prospectively or retrospectively (Balota, Yap, Cortese, & Watson, 2008; Hutchison, 2002; Neely, 1977; Neely & Keefe, 1989; Neely, Keefe, & Ross, 1989; Thomas, Neely, & O'Connor, 2012), though these processes are not mutually exclusive (Jones, 2010, 2012; Neely et al., 1989). *Prospective* mechanisms operate forward from prime to target, so that the prime word pre-activates the target word, thereby speeding its recognition. *Retrospective* mechanisms operate backward from target to prime, so that the prime and target words are considered together. For example, the prime "cat" could pre-activate the target "mouse" before the target is even presented (i.e., prospectively), or "cat" and "mouse" could be considered together after the target is presented (i.e., retrospectively). Theoretically, the complementary role activation that we hypothesize here could operate prospectively, retrospectively, or both.

In terms of prospective role activation, the prime word could activate its typical role, which would then activate its complementary role, thereby constraining the possible target words. To illustrate, "straw" activates *material*, which constrains the target to possible *object* concepts that could plausibly be made of straw. Thus "straw" would facilitate recognition of object words such as "hat", "man", and "mat", but not other words such as "love", "smile", and "hole." Although the number of possible *object* targets is large, it nonetheless excludes abstract concepts, and the physical features of “straw” further constrains its possible complements. By such a model, the activated relation prospectively constrains the semantic features that a complementary role-filler could plausibly have, thus speeding the affirmative judgment that a given target possesses those features (and hence must be a word). This prospective account essentially describes role activation as a selectional restriction, and indeed, this is consistent with recent views of selectional restrictions as early-acting constraints on conceptual knowledge activation (Hare et al., 2009; Matsuki et al., 2011; Khalkhali, Wammes, & McRae, 2012), and such selectional restrictions partially explain comprehension of noun compounds (Maguire et al., 2010). In fact, a similar form of selectional restriction can prime a sequence of thematic events: Lexical decisions to targets (e.g., “chew”) are faster following two thematically related primes (e.g., “marinate” and “grill”) than following two unrelated primes (Khalkhali et al., 2012).

Alternatively, complementary role activation could facilitate word recognition in a retrospective manner. After target presentation, the role activated by that target may be checked for complementarity with the role activated by the prime. Indeed, the target must be evaluated to determine whether it meets the constraints established by the prime-activated role. For instance, if the prime word does not adequately constrain the set of possible complementary target words, the target word itself would be critical for confirming whether and how (i.e., via which relation) the prime and target can be integrated. In fact, judging the plausibility of a noun-noun pair is crucial to comprehending or interpreting such pairs (e.g., Connell & Keane, 2006; Costello & Keane, 2000; Lynott & Connell, 2010; Murphy & Wisniewski, 2006; Wisniewski & Murphy, 2005). Likewise, such a plausibility judgement likely occurs during integrative priming, and this plausibility judgment must occur retrospectively because it cannot be completed until after target presentation. Note that such a retrospective component of integrative priming is fundamentally different from the well-established mechanism of semantic matching, as the present account is not based on association or similarity, nor does it appear to be controllable (see also Estes & Jones, 2009).

Thus, it seems likely that complementary role activation influences word recognition retrospectively, and it may also do so prospectively: The prime and its role may pre-activate a set of complementary features and roles, and subsequently the target and its role may be checked for relational complementarity with the prime and its role.

Based on the integrative priming obtained by Estes and Jones (2009) in a lexical decision task with neutral primes (********), we have argued here that integrative priming entails prospective and/or retrospective *facilitation* of the target. However, there also may be an *inhibitory* effect for targets following unrelated primes (Forster, 1981; Neely, 1991). Indeed, the use of a repetitive non-linguistic neutral prime like the asterisks used in Estes and Jones does not rule out an inhibitory effect (for further discussion and recommendations regarding use of neutral primes see McNamara, 2005). Thus, future integrative priming studies may include a more appropriate neutral prime condition (e.g., nonword primes) in order to better assess the extent of facilitation versus inhibition in integrative priming.

Finally, just as extant mechanisms of priming are not mutually exclusive (e.g., the three-process model; Neely et al., 1989; Neely, 1991), we view our proposed role activation mechanism as supplementary to other extant mechanisms. Any given word pair may be related in various ways to differing extents, and it is likely that multiple priming mechanisms operate simultaneously. For example, word pairs that are easily integrated but also are strongly associated (e.g., pumpkin pie) or co-occur frequently (e.g., tomato soup) may induce role activation and spreading activation, and depending on the situational parameters, may also induce compound cue retrieval. An important goal for future research is to determine whether (and if so, how) the various priming mechanisms interact during language comprehension.

Conclusion

To test whether integrative priming is controllable, we used stimuli that were unassociated, dissimilar, and unfamiliar as a phrase, and we used tasks that diminished or discouraged the use of relational integration. Nevertheless, robust and reliable integrative priming was indeed observed in both masked perceptual identification (Experiment 1) and Stroop color naming (Experiment 2). These results thus strongly suggest that relational integration can occur uncontrollably. Extant factors and mechanisms of lexical priming failed to explain integrative priming for these unassociated, dissimilar, and unfamiliar word pairs. Hence, these results suggest instead a new uncontrollable mechanism that may be based on a prospective complementary role activation and/or a retrospective plausibility judgment.

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Footnotes

[1] McNamara (2005) defined automatic processes as having a quick onset, occurring without intention or awareness. In this paper we have chosen to focus only on the intentionality of the process and therefore use the terms “uncontrollable” and “controllable” rather than the more commonly used “automatic” and “strategic.”

[2] To be clear, we are not arguing that the colour naming task measures only uncontrollable or “automatic” processes. On the contrary, colour naming is indeed susceptible to strategic influences (e.g., Besner, Stolz, & Boutilier, 1997). Our argument is merely that, under the specific conditions of our colour naming task (see Burt, 1999, 2002), lexical integration would act to *hinder* rather than facilitate responding. Thus, if lexical integration were controllable, participants should not engage in it and hence interference should not occur. Alternatively, if lexical integration is uncontrollable, then interference should be observed despite its presumed detrimental effect in this task.

[3] British English and American English spellings for two of the target nouns (‘colour → color’ & ‘maths → math’) were used interchangeably for obtaining measures of associability, similarity, integratability, and co-occurrence. British English spellings were presented during the experiment.

[4] Although this 1.0 difference in integrative ratings between the associative and integrative pairs does not seem large, it was a reliable difference ($p < .01$). Moreover, the integrative ratings for the associative items were reliably below the midpoint of 4.0, whereas they were reliably above this midpoint for the integrative items.

Table 1. Stimulus properties of associative, integrative, and unrelated prime-target pairs.

Property / Measure		Associative *M*	Associative *SD*	Integrative *M*	Integrative *SD*	Unrelated *M*	Unrelated *SD*
1. Association							
Nelson	Forward	0.37	0.14	0.02	0.01	0.00	0.00
	Backward	0.02	0.03	0.00	0.00	0.00	0.00
De Deyne	Forward	0.40	0.18	0.04	0.04	0.00	0.00
	Backward	0.05	0.07	0.01	0.01	0.00	0.00
2. Similarity		5.37	1.12	2.86	0.65	1.33	0.23
3. Integration		3.39	0.93	4.40	1.18	1.69	0.38
4. Global Co-Occurrence							
LSA		0.33	0.15	0.18	0.09	0.05	0.05
Hits		17.64	0.22	17.82	0.23	17.25	0.25
Predictability		0.39	0.06	0.24	0.06	0.26	0.06
5. Local Co-Occurrence							
Beagle		0.35	0.02	0.25	0.02	0.14	0.01
Hits		12.62	0.23	12.74	0.32	9.22	0.26
Predictability		0.00	0.00	0.00	0.00	0.00	0.00

Note. Association values are probabilities from the free association task, and range from 0 to 1. “Nelson” = Nelson et al. (2004). “De Deyne” = De Deyne et al. (2013). Similarity and integration values are ratings on a scale from 1 (low) to 7 (high). Global co-occurrence values are log transformed LSA cosines (Landauer & Dumais, 1997), log transformed Google hits without quotation marks, and raw Google conditional probabilities of the target given the prime without quotation marks. Local co-occurrence values are Beagle cosines (Mewhort & Jones, 2007), log transformed Google hits with quotation marks, and raw Google conditional probabilities of the target given the prime with quotation marks.

Figure 1. Procedure of perceptual identification task, Experiment 1.

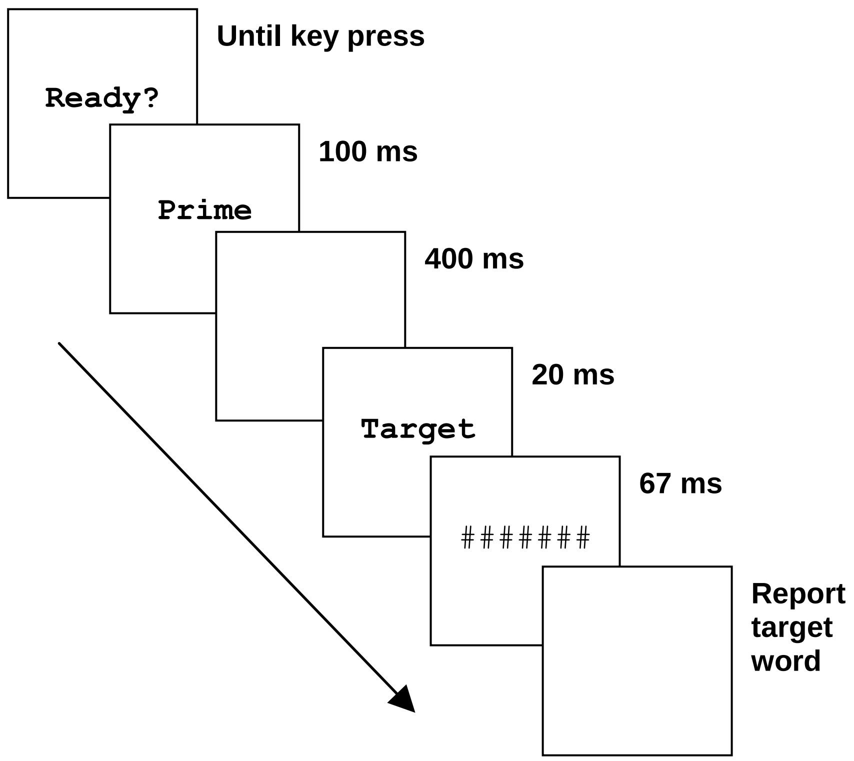
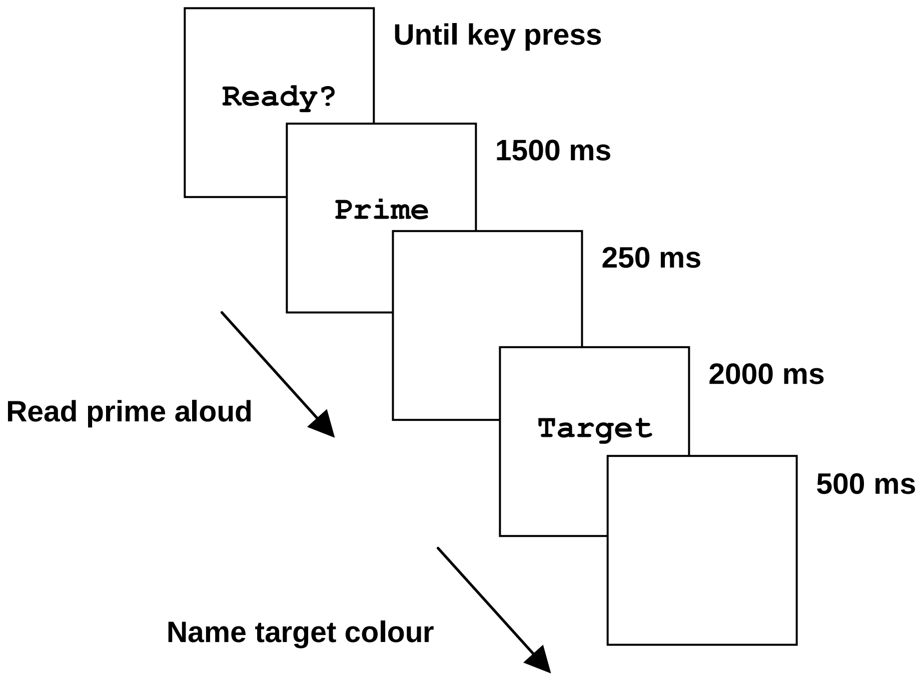


Figure 2. Procedure of colour naming task, Experiment 2.



Appendix A

Prime and target nouns used in Experiments 1 and 2.

Prime			
Integrative	Associative	Unrelated	Target
leak	breath	straw	air
celebration	alcohol	crayon	beer
lake	canary	trial	bird
corn	spread	literature	butter
wood	stool	cave	chair
dial	click	picket	clock
stain	pigment	nap	colour
stable	cattle	winter	cow
forest	shadow	fan	dark
canyon	oasis	loft	desert
stairway	rise	schedule	fall
chain	gate	lounge	fence
pillow	conflict	flannel	fight
lapel	lily	camel	flower
bowl	cod	torture	fish
summer	recreation	pendulum	fun
path	mower	revolution	grass
plastic	helmet	switch	hat
parade	trot	cafeteria	horse
plug	darkness	trip	light
theory	algebra	goat	maths
mammal	spill	weekend	milk
football	discomfort	meadow	pain
legal	folder	stable	paper
pool	festival	granite	party
peach	piece	clinic	pie
missile	helicopter	alphabet	plane
beach	chase	equation	run
industry	puff	pumpkin	smoke
territory	battle	dip	war
steam	ship	pasture	boat
square	prom	gas	dance
campaign	lunch	radio	dinner
pub	groceries	nitrogen	food
chlorine	fumes	video	gas
badge	bronze	shade	gold
glass	cottage	bait	house
trust	dollars	chimney	money
county	handcuffs	nest	police
lecture	doze	track	sleep
mushroom	stew	patrol	soup
gear	twig	banquet	stick
vacation	minutes	suede	time
fruit	limb	passenger	tree
toilet	splash	thesis	water