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Relations between emotion, illusory word perception, and orthographic repetition blindness: Tests of binding theory

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This study reports effects of meaning and emotion (taboo vs. neutral words) on an illusory word (IW) phenomenon linked to orthographic repetition blindness (RB). Participants immediately recalled rapid serial visual presentation (RSVP) lists consisting of two critical words (C1 and C2) containing shared letters, followed by a word fragment: for example, *lake* (C1) *brake* (C2) *ush* (fragment). For neutral critical words, participants often recalled C1, but not C2 or the fragment, reporting instead a nonoccurring or illusory word: here, *brush* (a blend of C2 and the fragment). Forward RB (defined as reduced report of orthographically similar C2s) was more common for neutral than for taboo C2s, and taboo IWs were reported significantly more often than were neutral IWs. Moreover, when both C2 and the potential IW were taboo, a new phenomenon emerged: Participants reliably reported both the IW and the intact C2. These and other results supported a binding theory of the IW phenomenon and orthographic RB.

This study examines effects of emotion on the report of unpresented or illusory words (Harris, 2001; Harris & Morris, 2000, 2001; Morris & Harris, 1999). This illusory word (IW) phenomenon occurs for immediate recall of specially constructed lists presented in an unusual manner—namely, rapid serial visual presentation (RSVP), where words and word fragments are presented on top of each other at about 100 ms per frame. The RSVP lists in IW studies consist of two critical words followed by a word fragment (e.g., *lake brake ush*), and participants often report the first critical word (C1), but not the fragment or the second critical word (C2). Instead they report strong perception of a nonoccurring or illusory word (IW) that blends C2 and the fragment. For example, they report *lake brush* instead of *lake brake ush* and express surprise that the IW *brush* was not in the list. As in this example, IW

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This paper is dedicated to Wayne Wickelgren (1938–).

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report is especially likely when C1 and C2 share one or more letters, but orthographic overlap is unnecessary: IW report also occurs when C1 and C2 share no repeated letters. Phonological overlap is also unnecessary: IW report occurs when letters in C2 must change their pronunciation in order to blend with the fragment and form the IW: for example, *threat*, the IW for the list *china cheat thr* (Harris & Morris, 2001). Visual factors are also malleable: IW report occurs when C1 and C2 differ in case, as in the list *LAKE brake ush*, and when the fragment and unrepeated or "leftover" letters in C2 are spatially unaligned (see Harris, 2003). Sequential order is likewise flexible: IW report occurs when one or more words separate C1 and C2 and when the fragment precedes C2, as in *lake ush brake*. The one essential factor seems to be presentation rate: IWs are not reported in RSVP studies with rates slower than about 150 ms per frame, and time pressure alone suffices to cause "letter migration IWs" such as *lice* and *lane* for brief single-frame presentation of the string *line lace* followed by a mask (Mozer, 1983).

Repetition blindness and the IW phenomenon

Only one theory currently addresses the report of IWs in RSVP lists—the visual-orthographic theory of Harris and Morris (2000)—and because the repetition blindness (RB) phenomenon plays a central role in visual-orthographic theory as well as in the present experiment, we begin with general overview of RB and its explanations.

RB and its process-explanations

RB refers to the reduced probability of encoding and recalling a unit (word, phonological segment, or letter) due to prior occurrence of the same unit in a rapidly presented word, list, or sentence (see, e.g., Hochhaus & Marohn, 1991; Kanwisher, 1987, 1991; Kanwisher & Potter, 1989, 1990; MacKay, 1969). Although orthographic RB is of central concern in the present research, we use lexical RB to illustrate the phenomenon because words have been the units of central concern in most RB theories and studies to date. When the sentence, "They wanted to play sports but sports were not allowed" is presented via RSVP at 150 ms/word or less, immediate recall is less likely for the second occurrence of *sports* than for the same word *sports* in the (nonrepeating) context, "They wanted to play ball but sports were not allowed" (Kanwisher, 1987). As in these examples, sentences in RB studies come in pairs that contain two critical words: a prior or "pretarget" word labelled C1 that differs within each sentence pair, and a target word or C2 that is identical within each pair and represents the unit of analysis or focus of interest. Studies using these procedures typically define RB as the difference between the probability of recalling repeated versus unrepeated targets.

Two fundamental processes have been proposed for explaining RB. One is an inhibitory process that follows activation of nodes representing lexical, phonological, and orthographic units. This "self-inhibition" process makes a node difficult to reactivate for a brief period of time, thereby reducing the probability of encoding a second instance of the unit during that period (see Hochhaus & Marohn, 1991, for a review of inhibition theories of RB). However, RB decreases linearly as a function of presentation time whereas nonlinearities would be expected under inhibition theories (see MacKay, Miller, & Schuster, 1994). RB also increases with ageing in normal older adults (see MacKay et al., 1994) whereas RB should decrease with ageing under inhibition theories because inhibitory processes become less effective with ageing in older adults (see, e.g., Birren & Woodruff, 1983; Hasher, Stolfus, Zacks, & Rypma, 1991; Hasher & Zacks, 1988; also McDowd, Oseas-Kreger, & Filion, 1995, for a review). Inhibition theories nevertheless remain viable for orthographic RB in RSVP paradigms because neither ageing nor presentation rate has been systematically manipulated in studies to date.

Other theories have proposed a different but equally fundamental process for explaining RB and repetition deficits more generally—namely, binding or connection formation. Under binding theories of RB, encoding a repeated word in a sentence requires two instances of connection formation involving one and the same lexical node. For example, when comprehending the sentence, "They wanted to play sports but sports were not allowed", the single lexical node for the repeated concept (*sports*) must quickly connect with two specific nodes—namely, "to play sports (verb phrase)" and "sports were not allowed (proposition)". However, the lexical nodes for unrepeated concepts—for example, *to*, *were*, *allowed*, and *ball* in the sentence, "They wanted to play ball but sports were not allowed"—become connected with only a single node. Now, binding mechanisms can quickly link different lexical nodes to their phrase nodes because one-to-one connections between different nodes can be formed *in parallel* (see Abrams, Dyer, & MacKay, 1996, for further details). However, binding mechanisms can only link the same node to two different nodes *in sequence*, making the "double binding" process that links the lexical node for a repeated word to two different phrase nodes relatively slow (see, e.g., MacKay et al., 1994). Of course, double binding is not a problem when presentation rates are slow enough that parallel (speeded) processing is unnecessary for accurate encoding, but no set delay is required before a second connection to a repeated lexical concept can be formed. Rather, forming the second or "delayed" connection simply becomes less likely as presentation time decreases because only some of the connections for encoding a sentence can be formed in the available time (for detailed theories incorporating binding assumptions, see Kanwisher & Potter, 1989; MacKay & Miller, 1994; and Wickelgren, 1965).

Under binding theory assumptions, graded factors that slow down the formation of word-to-phrase links will cause systematic increases in lexical RB. One of these graded factors is ageing: Normal older adults in general require more time than young adults to form new connections (see, e.g., MacKay & Burke, 1990), which explains why older adults exhibit greater RB than do young adults under binding theories (see MacKay & Miller, 1994; MacKay et al., 1994). Conversely, graded factors that facilitate or speed up the formation of word-to-phrase links will systematically reduce lexical RB under binding theories. One of these binding facilitators is specific to acoustic presentation of sentences, namely *prosody*. Prosody refers to the set of timing, stress, and pitch cues that listeners use when locating phrase boundaries in sentences (Levelt, 1990, pp. 365–412). By way of illustration, consider how timing (pauses and word duration) helps listeners encode the acoustic sentence, "*Lashley told me to go without hesitating*." If *go* is lengthened and followed by a pause, as in "*Lashley told me to go—without hesitating*", the listener will quickly link *without hesitating* to Lashley's manner of instruction. With reduced pausing and *go*-length, however, listeners must link *without hesitating* to the manner of *going*. This and other prosodic cues explain why rapid auditory presentation of sentences produced with normal prosody fails to induce repetition deafness (RD), the auditory analog of RB (see Miller & MacKay, 1994, 1996): Prosodic cues offset the extra time required to encode repeated words by specifying what words connect with what phrases in normal-prosody sentences. However, RD effects that closely parallel RB do occur with rapid auditory presentation of both *word lists* and *aprosodic* sentences (produced word by word with list-like prosody) because these stimuli lack the prosodic cues for speeding up the process of forming word-to-phrase links (see MacKay & Miller, 1996; and Miller & MacKay, 1996).

Also consistent with binding theory assumptions, RB decreases in magnitude when visual presentation procedures facilitate the process of binding words to phrases in sentences. Abrams et al. (1996) presented sentences using two RSVP procedures: phrase-congruent RSVP where each screen contained a single complete phrase or syntactic constituent, as in [*They wanted*] [*to play sports*] [*but sports*] [*were not allowed*] (where brackets enclose a phrase), versus phrase-incongruent RSVP where each screen contained nonphrases, as in [*They wanted to*] [*play sports but*] [*sports were not*] [*allowed*] (where brackets enclose nonphrases or parts of several phrases). As in these examples, the word sequence was identical in phrase-congruent and phrase-incongruent sentences, which were equated on average for presentation time per word, number of frames per sentence, mean number of words per frame, the serial position of pretarget and target words within the frames, and the absolute and relative "eccentricity" of target and pretarget words—that is, their degree of shift to the left or right of central fixation. Immediate recall results indicated a significant increase in RB for phrase-incongruent relative to phrase-congruent sentences, indicating that like RD in normal-prosody sentences, RB decreases in magnitude when phrase-congruent frames make it easier to form word-to-phrase links in sentences. Other results indicated that the standard or word-by-word RSVP procedure, where isolated words receive identical duration and between-word pauses (0 ms), yielded more RB than phrase-congruent sentences but less RB than phrase-incongruent sentences, suggesting that the unusual word-by-word prosody of standard RSVP may augment RB by slowing the formation of word-to-phrase links. However, the assumptions of RB binding theories have never been applied to the orthographic RB that occurs in the IW paradigm, where C2 report is reduced more when C1 and C2 contain repeated letters, as in *lake brake ush*, than when C1 and C2 contain no repeated letters (Harris & Morris, 2001; and Morris & Harris, 1999).

Visual-orthographic theory, IWs, and emotion

The visual-orthographic theory of Harris and Morris (2000) was designed to explain the relation between RB and IWs when repeated letters in C1 and C2 are "missing" or unreported due to orthographic RB in RSVP lists. Under visual-orthographic theory, orthographic RB and the IW phenomenon share a low-level locus involving letters, letter clusters, or visual word forms, but not phonology or word meaning: Orthographic RB occurs because activating C1 causes inhibition of its orthographic units for a brief period, inducing RB for the identical or repeated letters in C2 and thereby preventing perception of C2 as an independent word. However, the unrepeated or leftover letters in C2 do not suffer RB and can become activated in conjunction with the letters of the fragment, causing "bottom-up" activation of the IW in, say, a cortical area representing visual word-forms (see Niedeggen, Heil, Ludowig, Rolke, & Harris, 2003). The temporary inhibition that causes RB therefore readily explains why many fewer IWs are reported when C1 and C2 contain no repeated letters, and why no IWs are reported for presentation rates slower than about 150 ms per frame.

The present study manipulated word meaning in IW lists in order to test the assumption of visual-orthographic theory that word meaning plays no role in the IW phenomenon. C1s were always neutral in our RSVP lists, but C2s and potential IWs were either taboo or neutral (see Table 1 for example lists). Taboo words receive higher ratings than neutral words on scales representing negative emotional valence, and presenting taboo words incurs a transient increase in skin conductance, an unconscious index of emotional arousal (see, e.g., LaBar & Phelps, 1998). However, meaning rather than orthography triggers the emotional reaction and makes taboo words taboo: For example, the word *ask* is nonarousing and neutral in emotional valence despite sharing orthography with the taboo word *ass*. Visual-orthographic theory therefore predicts no effects of the emotion (taboo vs. neutral) of C2 or a potential IW on IW report.

A binding theory of emotion, list recall, and IW report

The present study also tested the predictions of a lexical-level binding theory that applies to sentence comprehension (MacKay, Stewart, & Burke, 1998b), to encoding for sentence production and list recall (MacKay, Burke, & Stewart, 1998a), to effects of emotion on word recall (MacKay et al., 2004), and to IW report. MacKay, Shafto, Taylor, Marian, Abrams, & Dyer (2004) spell out the binding theory assumptions that are relevant to the present 2 (C2 emotion: taboo vs. neutral) $\times$ 2 (IW emotion: taboo vs. neutral) design. Assumption 1 is that emotional arousal associated with taboo word meanings abruptly captures the binding mechanisms for forming new connections, thereby ensuring that taboo words are encoded for subsequent recall (see MacKay et al., 2004).

Assumption 2 is that binding processes for linking list context to the lexical node for word meaning play a critical role in orthographic RB and IW report: We recall particular words in a list via list-context-to-lexical node links, and recall of C1 but not C2 tends to occur because the list-context link for an identical or orthographically similar C2 cannot be formed quickly enough under RSVP conditions (see Abrams et al., 1996). Similarly, IWs are the usual outcome in IW experiments because binding list context to the already-formed lexical node for an IW takes less time than forming the additional bindings for representing the fragment and leftover C2 letters as distinct units and binding these nonwords to their list context for later recall.

Our lexical-level binding theory therefore addresses what words participants report in the IW paradigm, but not the processes that create IWs or cause RB. Nevertheless, by adopting the process assumptions of visual-orthographic theory without its structural assumption that word-meaning units are irrelevant to orthographic RB and IWs, binding theory generates four predictions for the present experiment. First, taboo C2s will be better recalled and less susceptible to RB than neutral C2s because emotion prioritizes the process of binding list context to the taboo C2 as an intact unit. Prediction 2 of binding theory concerns the probability of reporting C1 when C2 is neutral versus taboo. Because emotion-linked words abruptly capture the mechanisms for binding list context, a taboo C2 will cut short the time needed to bind the prior (neutral) C1 to its list context under RSVP conditions. Since list context acts as a retrieval cue for recall, this means that taboo C2s will reduce C1 recall, increasing the probability of reverse RB (defined as recall of C2 but not C1; see Whittlesea & Wai, 1997).

TABLE 1
The 40 lists, with mean recall as a function of condition and component type

Condition	*List number*	*Filler*	*C1*	*C2*	*Fragment*	*Possible IW*
C2 neutral–IW taboo	1	door	nap	cap	um	*cum*
	2	fan	roll	doll	yke	*dyke*
	3	food	hay	clay	it	*clit*
	4	home	bell	shell	it	*shit*
	5	little	brain	chain	ink	*chink*
	6	cable	river	sever	men	*semen*
	7	decide	brat	what	ore	*whore*
	8	office	thing	king	ike	*kike*
	9	feeble	sent	went	op	*wop*
	10	joke	bail	quail	eer	*queer*
Recall	*M*	0.987	0.633	0.432	0.200	0.268
	SD	0.034	0.244	0.197	0.184	0.206
C2 taboo–IW neutral	11	desk	uzi	*nazi*	tion	nation
	12	kids	tennis	*penis*	arl	pearl
	13	book	stress	*ass*	rt	art
	14	news	catch	*bitch*	ll	bill
	15	lose	snap	*crap*	own	crown
	16	year	pitch	*snatch*	ck	snack
	17	symbol	veal	*anal*	swer	answer
	18	club	buzz	*jizz*	nx	jinx
	19	great	tape	*rape*	ent	rent
	20	day	tangy	*orgy*	bit	orbit
Recall	*M*	0.948	0.558	0.613	0.097	0.113
	SD	0.085	0.232	0.236	0.120	0.115
C2 neutral–IW neutral	21	around	more	chore	alk	chalk
	22	mouse	bank	prank	int	print
	23	watch	thumb	crumb	isp	crisp
	24	paper	room	bloom	ast	blast
	25	leaf	well	smell	art	smart
	26	car	theme	scheme	ool	school
	27	table	face	race	ain	rain
	28	phone	five	drive	eam	dream
	29	stuck	side	pride	oof	proof
	30	cup	make	shake	ave	shave
Recall	*M*	0.952	0.583	0.499	0.152	0.252
	SD	0.072	0.217	0.218	0.186	0.146
C2 taboo–IW taboo	31	offer	lock	*cock*	unt	*cunt*
	32	honey	miss	*piss*	rick	*prick*
	33	how	luck	*fuck*	ag	*fag*
	34	week	bagger	*nigger*	p	*nip*
	35	ghost	saner	*boner*	obs	*boobs*
	36	spoon	lit	*tit*	wat	*twat*
	37	bar	epic	*spic*	lut	*slut*

(*continued*)

TABLE 1 continued

Condition	*List number*	*Filler*	*C1*	*C2*	*Fragment*	*Possible IW*
	38	ivory	port	*fart*	ggot	*faggot*
	39	house	buck	*dick*	ldo	*dildo*
	40	sleep	glossy	*pussy*	bic	*pubic*
Recall	*M*	0.939	0.411	0.568	0.052	0.258
	SD	0.076	0.194	0.190	0.102	0.148

Note: C1 = Critical word 1. C2 = Critical word 2. IW = Illusory word.

Prediction 3 is that participants will report more taboo than neutral IWs because the lexical node for taboo IWs triggers an emotional reaction that prioritizes the process of binding a taboo IW to its list context for subsequent recall.

Prediction 4 is that participants will report fewer neutral IWs when C2 is taboo than when it is neutral. The reason is that taboo C2s are rapidly bound to their list context as intact words, leaving no free-floating letters, whereas RB often tears neutral C2s apart, leaving free-floating letters that can become bound with the fragment to form neutral IWs.

The present experiment was not designed to evaluate how meaning and emotion affects *absolute* RB, defined as the difference in report of orthographically similar versus dissimilar C2s given report of C1 (see, e.g., Harris & Morris, 2000, 2001). Absolute RB has been the main focus in other studies and requires an unrepeated condition, where C1 and C2 share no common letters. However, we omitted this condition in the present study because taboo C2s reduced C1 report in our pilot studies, an outcome that complicates the measurement of absolute RB, and because including trials without repeated letters would have introduced unwanted floor effects, cut our power in half, and reduced the report of IWs, the primary focus of our predictions. Instead, the present study focused on *relative* RB, defined as recall of C1 but not C2, a joint recall measure that ensures perception of C1 (a prerequisite for RB in visual-orthographic theory). This relative RB measure proved useful for comparing the relative frequency of reverse RB versus forward RB (defined as recall of C1 but not C2) and for comparing the effects of emotion on report of the repeated letters in C2. In the Discussion section we relate the present binding theory to other theories that predict effects of semantics on absolute RB for orthographic and lexical units (e.g., Abrams et al., 1996; MacKay, James, & Abrams, 2002; MacKay et al., 1994; Masson, Caldwell, & Whittlesea, 1998, and Whittlesea & Wai, 1997).

Method

Participants

A total of 32 UCLA undergraduates (8 males, 23 females, aged 18–25 years, $M = 20.03$, $SD = 1.87$) participated for partial course credit. All reported normal or corrected-to-normal vision and had age-normal forward ($M = 7.09$, $SD = 1.28$) and backward ($M = 5.03$, $SD = 1.22$) digit spans. Data from one participant were unusable due to a computer recording error.

Materials

The materials are shown in Table 1: A total of 40 lists presented in lower case 36-point Chicago font against a light-grey monitor background. Each list began with a neutral filler word, followed by the critical words, C1 and C2, which shared the same word-final letters (e.g., *more–chore*), so as induce orthographic RB and increase the probability of IW report. The word fragment that ended each list formed the potential IW in combination with the unshared letter(s) of C2. C1 was always neutral, and the emotion (taboo vs. neutral) of C2 and the potential IW was crossed to yield four conditions with 10 lists apiece, labelled as follows in Table 1: C2 neutral with IW neutral, C2 taboo with IW neutral, C2 neutral with IW taboo, and C2 taboo with IW taboo.

For stimulus control purposes, 40 undergraduates used 7-point (1–7) scales to rate for relative familiarity and obscenity a large set of neutral and taboo words ($N = 438$) listed in Coltheart (1981), Bellezza, Greenwald, and Banaji (1986), and Jay (1992, pp. 143–151). From these 438 words we selected 40 neutral and 40 taboo words to serve as C2s and potential IWs in our lists. Table 2 shows the mean familiarity and obscenity ratings and length in letters and syllables for all 80 words. The taboo words involved socially proscribed profanities, insults, and sexual references and received higher obscenity ratings ($M = 3.74$, $SD = 0.984$) than the neutral words ($M = 1.05$, $SD = 0.091$), $t(78) = 17.244$, $p < 0.01$. Taboo and neutral words were matched for mean familiarity ratings ($M = 6.17$, $SD = 1.03$ vs. $M = 6.65$, $SD = 0.26$) and length in syllables ($M = 1.27$, $SD = 0.45$ vs. $M = 1.10$, $SD = 0.30$) and letters ($M = 4.3$, $SD = 0.82$ vs. $M = 4.75$, $SD = 0.71$).

Procedure

Participants knew that they would see rapidly presented lists that might include word fragments as well as words, and they wrote exactly what they perceived on a numbered answer sheet. Instructions emphasized that responses would be scored anonymously and that some lists would contain obscene or taboo words. Participants were then offered another ongoing experiment without taboo words, but none chose this option. After five practice lists with neutral C2s and potential IWs, the experimenter left the room in order to minimize possible biases against reporting taboo words. Participants then saw the 40 experimental lists in random order.

Each trial began with a 2000-ms row of asterisks (********), then a 15-ms blank screen followed by the filler, C1, C2, and the fragment for 100 ms each. Then came a row of question marks (???????) that masked the fragment and remained on the screen to cue recall. To begin the next trial, participants pressed the spacebar.

Results

All analyses involved item recall without regard for sequence. Figure 1 shows the effects of C2 emotion on the mean probability for two types of relative RB: forward RB (defined as recall of C1 but not C2) and reverse RB (recall of C2 but not C1). A 2 (RB type: forward vs. reverse) $\times$ 2 (C2 emotion: taboo vs. neutral) analysis of variance (ANOVA) on these data yielded no effects of RB type, $F < 1$, or C2 emotion, $F(1, 30) = 3.516$, $MSE = 0.0076$, $p = .071$, but a RB type $\times$ C2 emotion interaction, $F(1, 30) = 28.722$, $MSE = 0.021$, $p < .001$. This interaction reflected greater forward RB for neutral ($M = 0.4264$, $SD = 0.1630$) than taboo C2s ($M = 0.2581$, $SD = 0.1592$), $t(30) = 5.020$, $p < .001$, but greater reverse RB for taboo ($M = 0.3790$, $SD = 0.1662$) than neutral C2s ($M = 0.2698$, $SD = 0.1558$), $t(30) = 4.090$, $p < .001$.

TABLE 2
The taboo and neutral C2s and potential IWs, with mean familiarity and obscenity ratings, length in letters and syllables, and mean probability of recall

Condition	*Words*	*Mean familiarity rating*[a]	*Length in letters*	*Length in syllables*	*Mean obscenity rating*[a]	*Mean probability of recall*
Taboo C2	anal	6.19	4	2	3.44	.63
	ass	6.78	3	1	3.56	.63
	bitch	6.72	5	1	4.47	.84
	boner	6.66	5	2	4.00	.84
	cock	6.34	4	1	4.34	.41
	crap	6.75	4	1	2.38	.78
	dick	6.59	4	1	4.25	.78
	fart	6.75	4	1	2.00	.34
	fuck	6.81	4	1	4.88	.81
	jizz	4.38	4	1	3.00	.38
	nazi	6.75	4	2	4.09	.69
	nigger	6.78	6	2	6.13	.81
	orgy	6.75	4	2	3.91	.78
	penis	6.88	5	2	3.25	.53
	piss	6.78	4	1	3.00	.31
	pussy	6.53	5	2	4.98	.75
	rape	6.75	4	1	3.69	.47
	snatch	6.50	6	1	2.22	.38
	spic	4.06	4	1	3.16	.13
	tit	6.34	3	1	3.59	.53
Mean		6.40	4.3	1.35	3.72	.59
Neutral C2	bloom	6.53	5	1	1.00	.55
	cap	6.59	3	1	1.03	.59
	chain	6.78	5	1	1.06	.28
	chore	6.34	5	1	1.00	.03
	clay	6.53	4	1	1.00	.94
	crumb	6.41	5	1	1.00	.63
	doll	6.63	4	1	1.03	.34
	drive	6.78	5	1	1.00	.81
	king	6.53	4	1	1.00	.34
	prank	6.84	5	1	1.22	.66
	pride	6.81	5	1	1.00	.56
	quail	6.13	5	1	1.13	.34
	race	6.84	4	1	1.00	.22
	scheme	6.44	6	1	1.13	.38
	sever	6.31	5	2	1.28	.19
	shake	6.84	5	1	1.00	.44
	shell	6.84	5	1	1.00	.66
	smell	6.78	5	1	1.06	.75
	went	6.78	4	1	1.00	.47
	what	6.63	4	1	1.00	.16
Mean		6.62	4.65	1.05	1.05	.47

(*continued*)

TABLE 2 continued

Condition	*Words*	*Mean familiarity rating*[a]	*Length in letters*	*Length in syllables*	*Mean obscenity rating*[a]	*Mean probability of recall*
Taboo IW	boobs	6.72	5	1	2.91	.06
	chink	5.28	5	1	4.31	.19
	clit	6.16	4	1	4.03	.06
	cum	5.88	3	1	4.03	.25
	cunt	5.75	4	1	4.72	.38
	dildo	6.41	5	2	3.88	.06
	dyke	6.41	4	1	5.06	.31
	fag	6.69	3	1	5.34	.31
	faggot	6.56	6	2	5.59	.19
	kike	2.88	4	1	3.22	.19
	nip	5.59	3	1	2.44	.00
	prick	6.66	5	1	2.75	.38
	pubic	6.53	5	2	2.28	.00
	queer	6.59	5	1	4.50	.44
	semen	6.66	5	2	2.63	.41
	shit	6.88	4	1	3.75	.13
	slut	6.88	4	1	4.06	.75
	twat	4.44	4	1	3.19	.31
	whore	6.81	5	1	4.22	.66
	wop	2.91	3	1	2.56	.03
Mean		5.93	4.3	1.2	3.77	.25
Neutral IW	answer	6.81	6	2	1.19	.03
	art	6.72	3	1	1.00	.31
	bill	6.53	4	1	1.00	.06
	blast	6.53	5	1	1.03	.41
	chalk	6.81	5	1	1.00	.72
	crisp	6.66	5	1	1.00	.13
	crown	6.31	5	1	1.00	.03
	dream	6.75	5	1	1.06	.09
	jinx	5.56	4	1	1.16	.16
	nation	6.84	6	2	1.00	.03
	orbit	6.53	5	2	1.03	.06
	pearl	6.88	5	1	1.03	.06
	print	6.81	5.	1	1.00	.00
	proof	6.69	5	1	1.00	.09
	rain	6.97	4	1	1.31	.34
	rent	6.91	4	1	1.00	.25
	school	6.78	6	1	1.31	.34
	shave	6.78	5	1	1.03	.38
	smart	6.94	5	1	1.00	.09
	snack	6.84	5	1	1.00	.13
Mean		6.68	4.85	1.15	1.06	.19

Note: C2 = Critical word 2. IW = Illusory word.
[a]1–7 scales.

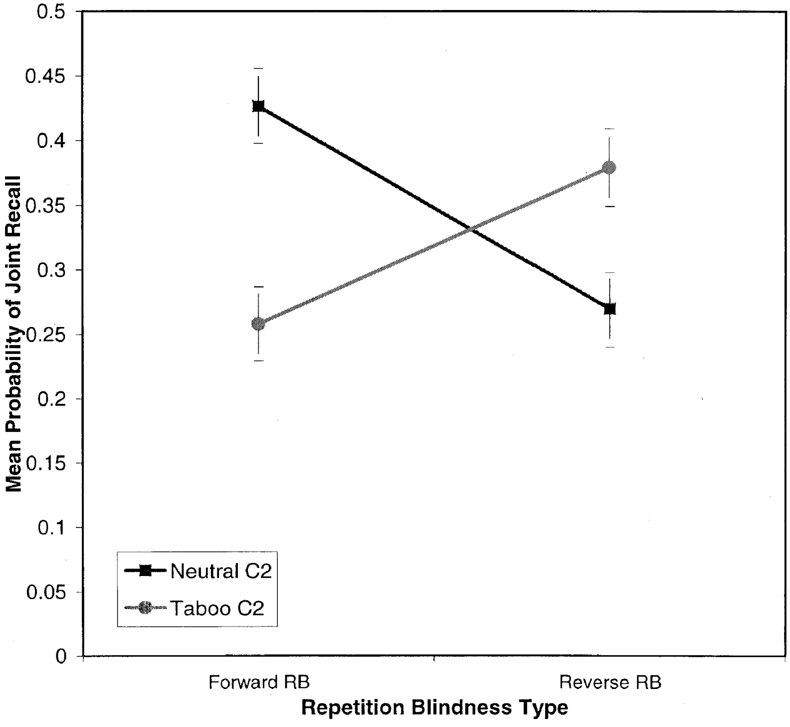

Figure 1. Mean probability of forward RB (joint recall of C1 and not C2) and reverse RB (joint recall of C2 and not C1) as a function of C2 emotion. Error bars indicate ±1 standard error.

This interaction was due in part to retroactive or "word-before" effects. C1 was better recalled when C2 was neutral ($M = 0.6226$, $SD = 0.2125$) than taboo ($M = 0.4694$, $SD = 0.2019$), $t(30) = 6.331$, $p < .001$, a word-before effect that was reliable even when C2 was not reported in recall, t(30) = 4.110, $p < .001$. We also observed several "two-before effects", where a taboo word reduced recall of neutral words presented two frames earlier. First, fillers were better recalled when C2s were neutral ($M = 0.9693$, $SD = 0.042$) than taboo ($M = 0.9435$, $SD = 0.063$), $t(30) = 2.269$, $p = .031$, a two-before effect, that was reliable when C2 was recalled (M neutral = 0.9741, $SD = 0.057$; M taboo = 0.9317, $SD = 0.079$), $t(30) = 2.654$, $p = .013$, but not when C2 was unrecalled, $t(30) = 0.071$, $p = .944$. Second, Cl was better recalled when the IW was neutral ($M = 0.6554$, $SD = 0.2173$) than taboo ($M = 0.5918$, $SD = 0.2104$), $t(30) = 2.214$, $p < .035$, a two-before effect that also failed to reach significance when the IW was unrecalled, $t(30) = 1.400$, $p = .172$.

Figure 2 shows the mean probability of C2 report as a function of emotion for C2 and the potential IW. A 2 (C2 emotion: taboo vs. neutral) × 2 (IW emotion: taboo vs. neutral) ANOVA on these data yielded an effect of C2 emotion, $F(1, 30) = 11.223$, $MSE = 0.043$, $p = .002$, with better recall of taboo than neutral C2s, and a marginal effect of IW emotion, $F(1, 30) = 3.997$, $MSE = 0.0243$, $p = .055$, with lower C2 recall for taboo than for neutral

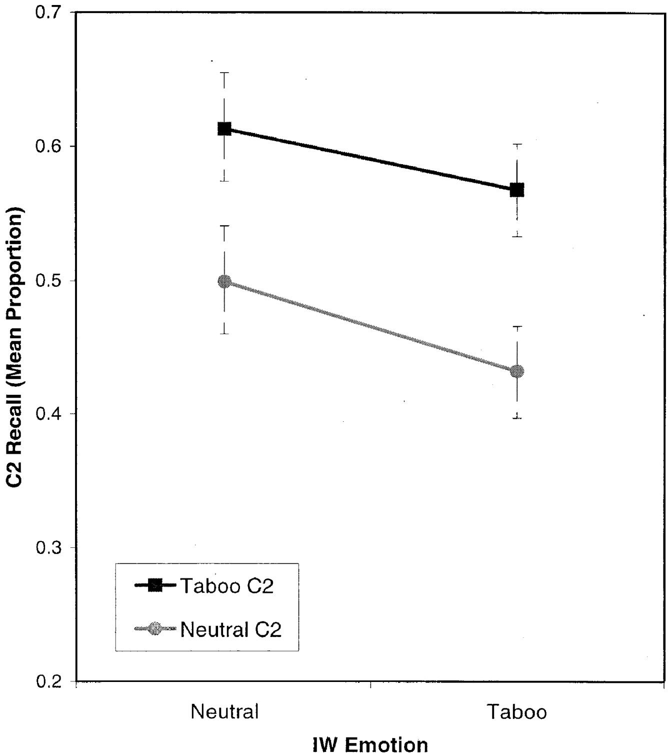

Figure 2. Mean probability of correct C2 recall as a function of C2 emotion and IW emotion. Error bars indicate ±1 standard error.

IWs. There was no interaction between C2 emotion and IW emotion, $F < 1$. The mean probability of reporting taboo C2s correlated reliably with mean obscenity ratings, $r = .414$, $p = .008$.

Figure 3 (left panel) shows the mean probability of IW report as a function of emotion for C2 and the potential IW. A 2 (C2 emotion: taboo vs. neutral) × 2 (IW emotion: taboo vs. neutral) ANOVA on these data yielded an effect of C2 emotion, $F(1, 30) = 8.333$, $MSE = 0.0205$, $p = .007$, with better IW recall for neutral than taboo C2s, and an effect of IW emotion, $F(1, 30) = 9.702$, $MSE = 0.0208$, $p = .004$, with better recall of taboo than neutral IWs. There was also a C2 Emotion × IW Emotion interaction, $F(1, 30) = 11.875$, $MSE = 0.0109$, $p = .002$, which reflected reliably better recall of taboo than neutral IWs following taboo C2s, $t(30) = 4.633$, $p < .001$, but not following neutral C2s, $t(30) = 0.288$, $p = .775$. The mean probability of reporting taboo IWs did not correlate reliably with their mean obscenity ratings, $r = .282$, $p = .078$.

Finally, joint recall of both C2 and the IW, or both the fragment and the IW, was rare (2.0–3.5% overall) but surprisingly systematic. Figure 4 (left ordinate) shows the mean probability of recalling both C2 and the IW as a function of emotion for C2 and

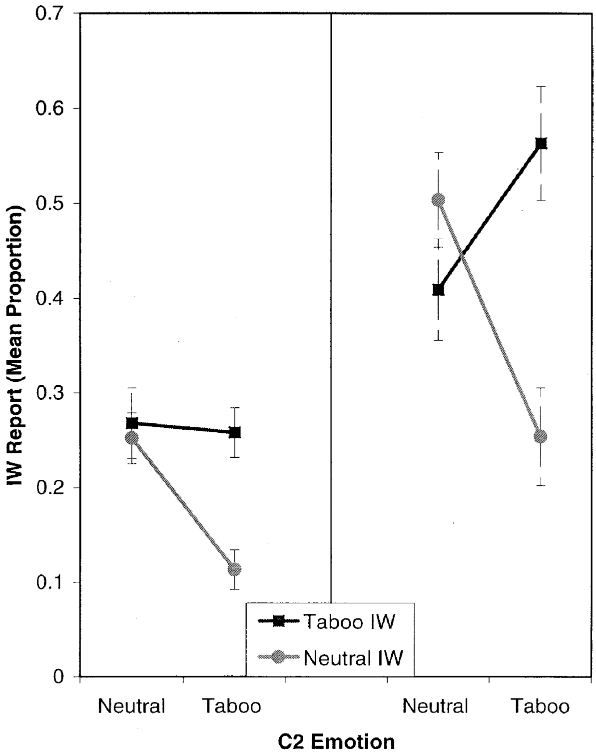

Figure 3. Mean probability of correct IW recall as a function of IW and C2 emotion for all data (left panel) and for instances where C2 was not recalled (right panel). Error bars indicate ±1 standard error.

the potential IW. A 2 (C2 emotion: taboo vs. neutral) × 2 (IW emotion: taboo vs. neutral) ANOVA on these data yielded an effect of IW emotion, $F(1, 30) = 5.479$, $MSE = 0.0033$, $p = .026$, with better joint recall of C2 and the IW for taboo than neutral IWs. No other effects or interactions were reliable, $F < 1$. Figure 4 (right ordinate) shows the mean probability of recalling both the fragment and the IW. A 2 (C2 emotion: taboo vs. neutral) × 2 (IW emotion: taboo vs. neutral) ANOVA on these data yielded an effect of IW emotion, $F(1, 30) = 4.444$, $MSE = 0.0016$, $p = .043$, with better joint recall of the fragment and the IW for taboo than neutral IWs, no effect of C2 emotion, $F(1, 30) = 2.069$, $MSE = 0.0025$, $p = .161$, and a reliable IW Emotion × C2 Emotion interaction, $F(1, 30) = 5.094$, $MSE = 0.00057$, $p = .031$, which reflected reliably greater joint report for taboo than neutral IWs with neutral C2s, $t(30) = 2.528$, $p = .017$, but not with taboo C2s, $t(30) = 0.571$, $p = .572$.

To test the generalizability of our taboo versus neutral stimulus categories, we conducted a one-way by-item analysis of covariance (ANCOVA) on the mean proportion correct recall using stimulus type (C2 or IW) as a covariate. This analysis replicated the superior recall of taboo ($M = 0.423$, $SD = 0.264$) versus neutral words ($M = 0.326$, $SD = 0.253$), $F(1, 76) = 4.254$, $MSE = 0.044$, $p = .043$. However, despite yielding similar mean recall for

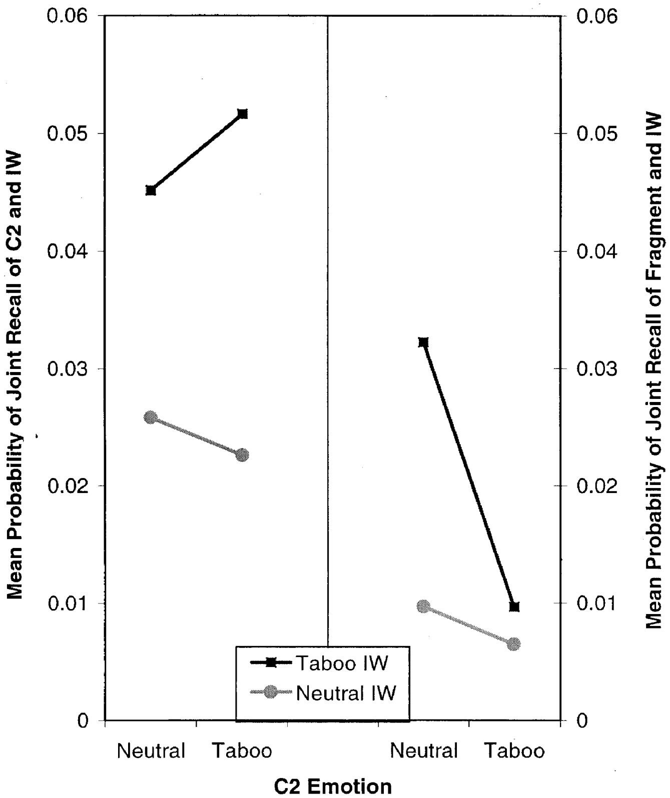

Figure 4. Mean probability of joint recall of IW and C2 (left ordinate) and mean probability of joint recall of the fragment and IW (right ordinate) as a function of IW and C2 emotion.

C2s and IWs, F_2 analogues of our two-way F_1 ANOVAs failed to achieve significance due to insufficient power (31 participants per cell in F_1 analyses vs. 10 words per cell in F_2 analyses).

Discussion

Overall report of IWs in the present study (about 22%) was low relative to Harris and Morris (2001), a difference attributable to four possible factors: recall procedures (written report in our study vs. oral report in Harris & Morris), presentation rate (100 ms/frame in our study vs. variable rates in Harris and Morris depending on participants' perceptual speed), emotion-induced instances of reverse RB in our study (which rendered the unrepeated C1 letters irrelevant to forming the designated IW), and unique aspects of stimulus lists in the two studies (given our F_2 results). Another possible factor is the relative unfamiliarity of taboo words as orthographic forms (since we primarily experience taboo words in acoustic rather than printed format), although orthographic frequency effects are currently unexplored in the IW paradigm.

Turning to theoretical issues, visual or orthographic factors clearly play an important role in the perception of IWs (see also Mozer, 1983). For example, Harris and Morris (2000, 2001) and Morris and Harris (1999) have conclusively shown that IW report is greatly reduced when C1 and C2 share no identical letters. Nevertheless, present results repeatedly violated a basic assumption of visual-orthographic theory: that word meaning plays no role in orthographic RB and IW report. IW report varied with C2 emotion and IW emotion, which indicates that word meaning influenced IW report because word meaning rather than orthography makes taboo words taboo. Also contrary to visual-orthographic theory, orthographically similar C2s were better recalled when taboo than when neutral,[1] which indicates that word meaning can influence the relative magnitude of forward RB, again because word meaning rather than orthography makes taboo words taboo (see MacKay et al., 2002, for a semantic effect in cross-language lexical RB).

We now consider two post hoc hypotheses that might be advanced for explaining present results. One is that arousal enables faster *activation* (rather than priority binding) of taboo words. However, a major result in MacKay et al. (2004) contradicts this emotion-linked activation hypothesis. If taboo words are activated faster than neutral words, one might expect faster lexical decision times for taboo than neutral words, but correct lexical decision times did not differ for taboo versus neutral words in MacKay et al. (Exp. 5).

Attentional resource concepts (e.g., Wells & Matthews, 1994, pp. 116–119) suggest a second post hoc hypothesis for explaining present results—namely, that novel, arousing, or emotion-inducing stimuli attract attention, and attention facilitates recall. However, if taboo words simply attract attention at time *n*, how can they impair the encoding of words occurring before time *n*, as in our three word-before effects: better recall of fillers and C1s preceding neutral than taboo C2s, and better recall of C1s preceding neutral than taboo IWs? This problem does not arise for other views of relations between attention and emotion. For example, MacKay and Ahmetzanov (2005) present evidence that attention focused on colour in the Stroop colour-naming task triggers binding mechanisms that help link the attended colour feature to salient aspects of context, consistent with the hypothesis that attention and emotion function similarly but independently in helping to bind features together.

Turning to the feature-binding role of emotion, the present data supported all four predictions of our lexical-level binding theory. First, C2s were less susceptible to forward RB when taboo than neutral. Second, C1 was poorly recalled when C2 was taboo, increasing the probability of reverse RB. Third, more taboo than neutral IWs were reported. Fourth, participants reported fewer neutral IWs following taboo than neutral C2s. Present results therefore support the basic assumptions of the lexical-level binding theory: (a) that emotional arousal associated with taboo word meanings abruptly captures the binding mechanisms for linking list context to the lexical node for word meaning, thereby facilitating the encoding of taboo words for subsequent recall; that forward RB (blindness for C2) occurs because the link from C2 to list context cannot be formed fast enough under RSVP conditions; (b) that reverse RB (blindness for C1) occurs because the link from C1 to list context cannot be

[1]This result is remarkable considering that some participants may have been biased against reporting taboo words. For example, one participant reported no taboo words (real or illusory), despite knowing that taboo words would appear and despite refusing the offer to participate in another experiment without taboo words.

formed fast enough under RSVP conditions; and (c) that IWs are the usual outcome in IW lists because list context can become bound to the already-formed lexical node for an IW faster than for the nonword units representing the fragment and leftover C2 letters.

We now relate our full range of results to other findings and hypotheses, including a possible extension of the lexical-level binding theory. Present results indicated better recall of C1 for neutral than taboo C2s even when C2 was not reported in recall. Under binding theory, this word-before effect suggests that a taboo word cuts short the process of binding an immediately prior (neutral) word to its list context even when the taboo word does not itself become successfully bound to its list context and reported in recall, an extension of the original word-before effect reported in MacKay et al. (2004).[2]

Present results indicated that filler words two frames before C2 were better recalled preceding neutral than taboo C2s, but only when C2 was reported in recall. Similarly, C1s two frames before the fragment (and potential IW) were better recalled preceding neutral than taboo IWs, but only when the IW was reported in recall. Under binding theory, these two-before effects suggest that successful encoding of a taboo word cuts short the process of binding a (neutral) word to its list context two words prior, even when the taboo word is illusory (an extension of the original two-before effect reported in MacKay et al., 2004). Present results also indicated that taboo IWs marginally reduced C2 recall, a weak word-before effect resembling the reliable word-before effects discussed previously.

Present results indicated poorer recall of neutral IWs following taboo than neutral C2s, an effect with two possible explanations under binding theory. One is that emotion facilitates the encoding of taboo C2s as intact words, leaving no leftover letters for forming a neutral IW. A second explanation follows from the large "word-after" effect reported in MacKay et al. (2004), where taboo words reduced immediate recall of subsequent neutral words. Under this "word-after hypothesis", binding mechanisms gave priority to encoding taboo C2s in the present study, leaving insufficient time under RSVP conditions to bind the subsequent (neutral) IW to its list context for later recall.

Present results indicated that taboo IWs were reported with higher probability than neutral IWs, a main effect with two possible explanations. One is that C2 and the fragment transmit priming to the lexical node for the taboo IW, triggering an emotional reaction that captures the binding mechanisms for encoding the taboo IW. The second explanation derives from effects of semantic priming on IW report (see Niedeggen et al., 2003). By triggering similar emotional reactions, taboo C2s may prime taboo IWs in the internal lexicon, and neutral C2s may prime neutral IWs (which may also explain why taboo IWs were only reported reliably more often than neutral IWs when C2s were taboo). To examine this issue further, we reanalysed IW report excluding instances where C2 was reported. Figure 3 (right panel) shows the results: a strong crossover interaction (reliable at $p < .001$), indicating better recall of IWs that shared the same emotional valence (taboo vs. neutral) as the

[2]The original MacKay et al. (2004) word-before effect involved immediate recall of lists containing orthographically unrelated words presented at 170 ms/word, with two taboo words intermixed among four neutral words at unpredictable positions in each list. Tulving (1969) reported a similar "retrograde amnesia effect" or reduction in recall of the prior word during quasi-free recall of RSVP lists containing a single "high priority" item.

(unreported) C2. This interaction suggests that emotional-valence priming from unreported C2s may influence IW report and comports with other indications that emotional valence influences information processing without awareness (see Bargh, Chaiken, Govender, & Pratto, 1992). However, this priming hypothesis must be considered speculative in the absence of direct RSVP evidence for emotional-valence priming.

Extending binding theory to orthographic processes

Systematic recall of both C2 and the IW in the present data contradicted two basic process assumptions of visual-orthographic theory. One contradicted assumption was that RB causes IWs by ripping C2 apart, thereby supplying leftover letters for forming the IW. Recall of both C2 and the IW indicates that IWs are reported even when RB does not rip the C2 apart and no leftover letters exist for forming the IW. The frequent report of IWs in conditions where C1 and C2 do not share repeated letters (see, e.g., Harris & Morris, 2001) likewise indicates IW report in the absence of RB-induced leftover letters. The second contradicted assumption was that activating C1 causes total blindness for the repeated or shared letters in C2: The frequent recall of C2 in the present study would not have occurred with total blindness for the repeated or shared letters in C2. Systematic recall of both the fragment and the IW indicates further that activating the fragment does not prevent activation of identical orthographic units in the subsequent IW, analogous to the orthographic inhibition assumed to cause RB in visual-orthographic theory. For the list *lake brake ush*, if perceiving the letters *ake* in *lake* inhibits *ake* in *brake*, then perceiving the letters *ush* should inhibit *ush* in *brush*, contrary to present results.

Although one could perhaps defend the unsupported assumptions of visual-orthographic theory by adding further assumptions (e.g., a "clean-up network" for matching degraded visual input to types in long-term memory; see Mozer, 1991), we undertake a different approach: to develop an extended binding theory that explains IW formation and orthographic RB using assumptions analogous to those discussed in the Introduction for explaining lexical RB in sentences. Under these new, supplementary assumptions, orthographic RB occurs because report of both C2 and C1 requires that units representing identical (repeated) visual events become bound to two different lexical nodes. For example, to accurately encode *roll* (C1) and *doll* (C2) in the list *roll doll yke*, units representing low-level visual events for *oll* must become bound to the lexical nodes for *roll* and *doll*. However, this "double binding" process is sequential and slow, and it often fails to occur at 100 ms/word, so that with neutral critical words, C1 but not C2 is usually encoded as an intact word and reported in recall, an instance of orthographic RB.

By contrast, IW report requires that different visual events for the fragment and unrepeated C2 letters become bound to the IW node, a process that is irrelevant to the double binding constraint because binding mechanisms can link different nodes in parallel to a single node. For the list *lake brake ush*, low-level visual events for the unrepeated cluster *br* in *brake* and the fragment *ush* can rapidly become bound to the lexical node for the IW, *brush*.

Now, under our earlier assumption that emotional reactions ensure priority for binding processes involving taboo words, our extended binding theory readily explains the superior joint recall of C2 and a taboo IW, or the fragment and a taboo IW: Because taboo words quickly capture the binding mechanisms, the double binding required to represent the C2 and a taboo IW containing C2 letters, or the fragment and a taboo IW containing the fragment, can sometimes occur at 100 ms/frame.

Besides explaining present results, our extended binding theory focuses attention on off-line processes in RB and IW paradigms—for example, retroactive effects such as the present reverse RB and word-before effects, which are difficult to explain in a strictly left-to-right bottom-up model (see also Whittlesea & Wai, 1997). Our extended binding theory also suggests a new explanation for why time pressure alone suffices to cause IWs: Letters can become bound to the wrong locations in a string such as *line lace* when insufficient time is available, causing IWs such as *lice* and *lane* (see Mozer, 1983). Needless to add, lexical guesses based on fragmentary perception may also play a role in the report of "letter migration" IWs.

Finally, our extended binding theory predicts that IWs will decrease when binding processes are facilitated and will increase when binding processes are made more difficult, as is the case with RSVP, where words and nonwords are superimposed on top of each other: Relative to normal left-to-right reading, RSVP increases binding difficulties by inducing low-level visual masking, perception of illusory movement, uncertainty regarding the sequence of words and nonwords, and spatial uncertainty regarding positions of the letters in the stimuli. Our extended binding theory also predicts effects of novelty on IW report because binding processes are necessary for representing novel or unfamiliar aspects of experience, but not familiar aspects (see, e.g., MacKay & James, 2001, 2003). For example, binding theory predicts that IWs will increase when the word fragments in IW lists are unfamiliar units (e.g., *nx* and *ggot*), rather than familiar; units (e.g., *men* and *art*, see Table 1). Familiar syllables such as *men* and *art* are readily activated and bound to their list context, unlike unfamiliar units such as *nx* and *ggot*, where veridical representation requires the formation of new nodes with new connections or bindings at orthographic as well as list context levels, and postperceptual report of these units requires new top-down connections at phonological levels.[3]

In conclusion, we agree with Harris and Morris (2001) that orthographic RB and the IW technique have proven useful for probing sublexical representations. The present results also suggest that this technique is useful for probing higher level representations and the effects of meaning-linked emotions on the fragile memories formed under RSVP conditions. The emotion variable may also prove useful for understanding other types of binding, and other tasks and phenomena, orthographic RB and the IW phenomenon being just one example.

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[3]However, phonology may play little role in fragment perception because the time required to produce pronounceable (let alone unpronounceable) fragments probably exceeds the entire duration of an IW list presented at 100 ms/frame. Moreover, report of the familiar C1s and C2s in IW experiments does not require new top-down phonological connections because these connections were formed when these words were learned during childhood.

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