Grammatical intuitions about irregular verb inflections

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If people possess a rule that the root of a verb plus *-ed* produces the past tense, why does this rule produce an unacceptable form when applied to an irregular verb (e.g., *comed*)? One possibility is that the unacceptability of *comed* is the result of lexical priming. That is, *comed* primes the correct form *came*, and the awareness of *came* causes *comed* to be perceived as unacceptable. If so, then the acceptability of a misinflected form should be determined by the factors that influence the priming of its correct form, such as the frequency and hence speed of retrieval of its correct form. Three experiments were conducted. In Experiment 1, subjects were faster to reject misinflected irregular verbs when the correct irregular form had a higher frequency than when it had a lower frequency. Furthermore, the higher the frequency of the correct form, the more unacceptable the misinflected form seemed. Experiment 2 used the naming task to confirm that the presentation of a misinflected form facilitated the naming of its correct form. In Experiment 3, subjects were faster to accept an irregular verb when it was primed by a misinflected irregular verb than with a correct regular verb. This was taken as evidence that the misinflected irregular verb accesses the correct form.

How are past tense verbs encoded in memory? Are the present and past forms of each verb encoded as separate lexical entries (e.g., *walk, walked; borrow, borrowed*), or is only the present root form encoded, and we recognize and generate the past tense by using the rule that adds *-ed* to create the past form? For regular verbs, the latter view seems immediately more plausible because we can obviously generalize the *-ed* ending to new verbs. Indeed, there is good evidence for morphological decomposition in the lexicon (Caramazza, Laudanna, & Romani, 1988; Morton, 1979).

How then are irregular verbs (e.g., *come, came; buy, bought*) encoded? One possibility is that they are generated by rules that are not very productive (Taft, 1979). A second possibility is that irregular verbs have both past and present forms encoded as separate lexical entries because both

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are encountered often enough to establish themselves, and there is no general rule to apply to the present form to derive a past form (Pinker, 1984). A third possibility is a connectionist account that does not distinguish between regular and irregular inflection and does not explicitly represent lexical items or inflectional rules but learns a mapping between roots and past tense forms (MacWhinney & Leinbach, 1991; Plunkett & Marchman, 1993; Rumelhart & McClelland, 1986). The experiments reported here were motivated by the mixed model in which the regular form is generated by a rule and the irregular forms are stored as lexical items. The other hypotheses is considered in the *General Discussion.*

However, this account raises an interesting question. If we use a rule to recognize regular past tense verbs, then why are misinflected irregular verbs (e.g., *comed, buyed*) perceived as unacceptable? This is a different question from why irregularly inflected verbs are acceptable, which presumably is the result of hearing them often enough. But this fact by itself would imply only that irregular verbs have two forms: the irregular form, established by its frequency in the language, and the regular form, which conforms to a universal rule of the language.

One answer is the unique entry principle (Pinker, 1984; Pinker & Prince, 1988). It starts with the assumption that a general rule such as *past(X) = X+ed* exists for regular verbs such as *walk* and *borrow,* but specific rules such as *past(come) = came* are used for irregular verbs such as *came* and *bought.* The unique entry principle is that a specific rule blocks the more general regularizing rule. However, this raises the question of why the unique entry principle should be part of a person's language competence. When this question is asked, it becomes clear that the unique entry principle is not an explanation of the unacceptability of *comed* and other irregular verbs with regular endings but a restatement of the phenomenon.

To see that the unique entry principle, as it currently exists, is merely a restatement of the phenomenon, consider to what other data it has been applied or can be applied. The more specific rule that generates *unhappy* does not block the more general rule that generates *not happy.* The more specific rule that generates *workman* does not block the more general rule that generates *worker.* Of course, these cases are distinguishable from *came–comed,* and an expanded unique entry principle could distinguish them. The point is that no such expanded principle exists yet. The hypothesis presented here may be considered such an expansion. That is, it may be taken as a description of the cognitive mechanism that makes the unique entry principle a part of a person's language competence.

The hypothesis considered here is that when a misinflected irregular verb is encountered, it activates, via its links to the root entry, the correct irregular form. For example, when *comed* is presented, *came* is activated as well. It is the activation of the correct form that leads to the intuition that the misinflected form is not acceptable. Therefore, the unacceptability of misinflected verbs is a consequence of morphological priming. Notice that three conditions must be satisfied for morphological priming to lead to the intuition that the priming form is unacceptable. First, the priming and primed forms must occupy the same syntactic context. Even if *walk* primes *walks,* because they occupy different syntactic contexts there is no reason to intuit that one is an alternative to the other in the same context. Second, the words must have the same meaning. Even if *doctor* primes *nurse,* because they have different meanings there is no reason to intuit that one can be substituted for another. Third, the priming form must have a zero frequency, and the primed form must have a nonzero frequency. Even if *perhaps* primes *maybe,* they are both well established in memory through usage. However, *comed* is perceived as novel, whereas *came* is perceived as familiar. It is the intuitive novel versus familiar distinction between the prime and primed that is rationalized (after the proper education) as the unacceptability of *comed.* Therefore, this judgment is made when both the presented *comed* and primed *came* have entered working memory. It is based on the perceived novelty of *comed* and perceived familiarity of *came.* Clear counterevidence to this hypothesis would be if people routinely knew that *comed* was unacceptable but could not think of the correct form, *came.*

In fact, people do not always treat misinflected irregular words as deviant. Young children go through a period lasting from age 2 into the school-age years when they produce overregularized (e.g., *comed*) as well as correct (e.g., *came*) forms (Marcus et al., 1992). The priming hypothesis provides a natural account of this phenomenon. Early in life *comed* does not prime *came* reliably enough to always alert the speaker to reject *comed* during the preparation of an utterance.

If the priming hypothesis is correct, then factors that influence the priming of the correctly inflected form may influence the acceptability of the misinflected form as well. For example, the higher the frequency of the correct form, the more quickly it is accessed and the more familiar it is. The greater familiarity should lead to a stronger perception of unacceptability for the misinflected form. For example, *comed* would be perceived as less acceptable than *swimmed* because *came* is a more familiar word than *swam.* In fact, the more often a parent uses an irregular form, the less often the child overregularizes it (Marcus et al., 1992).

Furthermore, there is much evidence that priming between morphologically related words occurs in adults (Forster, Davis, Schoknecht, &

Carter, 1987; Fowler, Napps, & Feldman, 1985; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Stanners, Neisser, Hernon, & Hall, 1979; Stolz & Besner, 1998), including between a regular verb and its past form (e.g., *manage-managed*). Furthermore, Grainger and Ferrand (1996) observed robust effects of phonologically related nonword primes in both lexical decision and perceptual identification tasks. The effect of nonwords found by Grainger and Ferrand is predicted by the hypothesis of Fowler et al. that all priming, including so-called lexical repetition priming, actually occurs at a sublexical level. That is, it occurs at the level of roots and inflections (although Fowler et al. do not specifically call this level morphemic). As Fowler et al. point out, their finding that *manage, management,* and *manageable* all prime each other as strongly as *manage* primes itself is inconsistent with an account of priming that occurs purely at the lexical level because these are different parts of speech that are not heard together. Fowler et al.'s hypothesis also predicts that *comed* primes *came,* and this result would be consistent with those of Grainger and Ferrand. But there is no specific evidence that a misinflected irregular verb such as *comed* primes its correct form, *came.* So the priming hypothesis has not been specifically tested for misinflected irregular verbs.

The purpose of this study was to test the predictions of the priming hypothesis. In Experiment 1, we manipulated word frequency to see whether it was correlated with the speed to reject a misinflected verb and the degree of its perceived unacceptability. The second and third experiments used a word reading task and a grammatical judgment task, respectively, to determine whether misinflected verbs primed their correctly inflected forms.

EXPERIMENT 1

Experiment 1 investigated intuitions about misinflected irregular verbs (*comed, swimmed*) to determine whether the unacceptability of such items was a function of the frequency of the correct form. The priming hypothesis predicts that when *comed* is encountered, the high-frequency correct form *came* is rapidly primed by the embedded verb *come.* The relationship between word frequency and lexical access, particularly as measured by lexical decision, has been well established in the lexical processing literature (e.g., Forster, 1990). The priming hypothesis predicts that because the correct form *came* is accessed so quickly, the incorrect form *comed* will be rejected quickly. Also, because *came* is more familiar than *swam, comed* will be perceived as more unacceptable than *swimmed.* To provide converging evidence for both parts of this prediction, two tasks were used. The first was a speeded grammatical judgment task measuring how quickly a misinflected form would be rejected. The second task was a subject-paced assessment of how "good" a word sounded on a 5-point scale to determine whether some misinflected forms sounded worse than others.

Each inflected verb had to be assigned to a frequency of occurrence in the English language. Determining the appropriate frequency for each verb inflection was problematic because the inflection systems of all irregular verbs are not comparable. Most verbs have the same form for the past and past participle (e.g., *made*), but some verbs have different forms (e.g., *ate* and *eaten*). In comparing these verbs it was not obvious whether to just consider the frequency of the simple past or to combine forms in some manner. Therefore, a variety of measures were used to empirically determine which would provide the best fit for the reaction time (RT) data. Using the frequency values from Francis and Kucera (1982), each verb was assigned four frequency classifications according to the log frequency of all its verb forms, its simple past form, its past participle form, and its simple past and past participle forms combined. For example, *sended* has a frequency count of 253 for all its verb forms, 69 for its simple past form, 75 for its past participle form, and 144 (i.e., 69 + 75 + 144) for its simple past and past participle forms combined (combined past). Each of these four frequency classifications was an attempt to measure the frequency of the past form. The most direct measures of the past form are that of its simple past form and its combined past forms. However, if one were to assume that no verb is more or less likely to be used in the past tense than any other, so that the underlying population frequency of the past form of a verb is highly correlated with its total frequency, then the indirect measure of the frequency of all its verb forms would be a better measure of the frequency of the past form because it is based on a larger number of observations. Verbs in each frequency classification were further categorized according to four frequency levels: high (words with 1,000 per million or more), moderate (less than 1,000 and greater than or equal to 100 per million), low (less than 100 and greater than or equal to 10 per million), and very low (less than 10 per million).

A second factor that could influence RT is the degree of morphological difference between the root of a verb and its inflected form. Therefore, each verb was classified according to the form that its inflection takes: a completely different word (e.g., *go/went*), a change in its root (e.g., *come/came*), or no change in its root (e.g., *cut/cut*). A fourth classification variable was used to identify the verbs that contained an embedded verb (e.g., *befell/fell*).

METHOD

Subjects

Forty-eight Rutgers University undergraduate students who were native speakers of English participated in the experiment for credit in general psychology. The subjects were tested individually on the same computer. The number of subjects was dictated by the planned analysis. RT and grammatical ratings were to be correlated with word frequency over 117 items. Forty-eight subjects contributing to each data point ensured that the data points would be reliable.

Materials

The 124 misinflected irregular verbs and 109 regular verbs were combined into a single experimental list. The irregular verbs comprised approximately 70% of the irregular verbs of English. The 109 regular verbs were familiar, had similar spelling patterns, and rhymed with the irregular verbs (e.g., *care, bear; end, spend*). For the moderate-, low-, and very-low-frequency irregular verbs the regular verbs were matched in frequency. But there are no high-frequency regular verbs to match with the irregular verbs. In addition, 12 verbs were not on the experimental list and were used as practice items.

Procedure

Subjects were told that they would see a word on a computer screen and that they should press the "yes" key if it was grammatical and the "no" key if it was ungrammatical, as quickly as possible without making errors. For half the subjects, "yes" was on the "f" key and "no" was on the "j" key. For the remaining half, the assignment was reversed. Subjects were then asked to rate how "good" the word sounded, using a 5-point scale ranging from 1 (*very poor*) to 5 (*very good*). After this rating judgment was made, a 500-ms delay ensued during which the screen was blank before the presentation of the next stimulus. RT was measured from stimulus onset to the depression of the "yes" or "no" key, which also terminated the presentation of the word. RTs exceeding 3,000 ms (less than 2% of the data) were converted to an upper limit of 3,000 ms.

Each subject completed 12 practice trials, which did not include any of the verbs in the experiment. Then they completed the 245 test trials, which were presented to them in random order. Every subject received a different random order. Halfway through the test sequence there was a pause. Subjects could rest for as long as they wanted during the pause before reinitiating the test sequence. All subjects chose to pause for only a few seconds. Each subject was tested individually and needed about 45 minutes to complete the experiment. Items were presented on the screen of a personal computer. Micro Experimental Laboratory (MEL) software was used to control stimuli presentation and data collection.

RESULTS AND DISCUSSION

Subjects agreed 94% of the time that correctly inflected regular verbs were grammatical and agreed 87% of the time that misinflected irregular verbs were ungrammatical. Table 1 shows the mean RT for correct decisions about regular and irregular verbs in each (all verb forms) frequency category as well as the error rate for each category. Table 2 shows the mean grammatical rating for each type of verb in each frequency category. The results were indistinguishable when the verbs were partitioned according to the other three frequency classifications. When the data where further partitioned by type of irregular verb, the same effects were observed for all three kinds of verbs; a change in root (e.g., *come/came*), no change in root (e.g., *cut/cut*) and embedded (e.g., *befell/fell*). The verb *go* is the only verb with a completely different past, so there was not an item set over which to make a frequency analysis for this classification.

The items were ordered on an inflection form dimension on the basis of the similarity between the regular ending and the correct ending of the verb. Regular verbs were assigned a value of 0 because the regular ending was the correct ending. Next, root change verbs were assigned a value of 1 because of the large mismatch between the regular ending and the correct ending. Finally, no–root change verbs were assigned a value of 2 because of the small mismatch between the regular ending and the correct ending. The rationale for this ordering was the ubiquitous finding of comparison tasks that matches are faster than large mismatches, which are faster than small mismatches. The different word category was omitted from the inflection form dimension, and hence from the subsequent correlational analysis, because it consisted of only a single verb, *go*. Therefore, it consisted of only a single data point that was necessarily based on many fewer observations than were the data for other categories. The embedded verb category was also necessarily omitted from the inflection form dimension because these two-syllable verbs added a confounding variable when ordered along a dimension with one-syllable verbs.

Table 1. Mean response time and percentage error (and standard deviation) in ms to correctly judge the grammaticality of regular verbs ("grammatical") and misinflected irregular verbs ("ungrammatical") as a function of the frequency classification of the correct form of the verb

	Verb type			
	Correct regular ("grammatical")		Misinflected irregular ("ungrammatical")	
	Response time	Error (%)	Response time	Error (%)
High frequency	—	—	1,114 (59)	5 (3)
Moderate frequency	1,085 (137)	4 (3)	1,240 (123)	11 (8)
Low frequency	1,164 (139)	5 (4)	1,379 (130)	12 (17)
Very low frequency	1,295 (159)	10 (8)	1,448 (140)	16 (15)

Table 2. Mean rating (and standard deviation) of regular verbs ("grammatical") and misinflected irregular verbs ("ungrammatical") as a function of the frequency classification of the correct form of the verb

	Verb type	
	Correct regular ("grammatical")	Misinflected irregular ("ungrammatical")
High frequency	—	1.32 (.19)
Moderate frequency	4.70 (.18)	1.47 (.24)
Low frequency	4.67 (.18)	2.03 (.72)
Very low frequency	4.48 (.25)	2.43 (.88)

Note. 1 = very poor; 5 = very good.

Table 3 is the correlation matrix for the four dependent variables (total RT, correct RT, accuracy as measured by percentage correct, and grammatical rating) and for the five independent variables (inflection-form and the four frequency measures). The correlations are based on 117 data points because, as mentioned earlier, *go* and the six items from the embedded verb category were excluded from the analysis. Each of the 117 data points for the four dependent measures was the mean of the responses of all 48 subjects except correct RT, which, by definition, was based on only correct responses. In Table 3, notice that the correlation between total and correct RT was .96. So in subsequent analyses only correct RT was used, which is the standard practice in RT studies. Also, notice that of the four frequency measures, that of all verb forms had the highest correlation with the dependent variables, RT, and gram-

Table 3. Correlation matrix for all variables in Experiment 1

	1	2	3	4	5	6	7	8	9
1. Total response time	1.00								
2. Unacceptable response time	.956*	1.00							
3. Accuracy rate	−.573	−.650	1.00						
4. Grammatical rating	−.096	−.150	.294*	1.00					
5. Inflection form	.259*	.317*	−.306*	−.833*	1.00				
6. All verb forms	.447*	.381*	−.126	.466*	−.280*	1.00			
7. Simple past	.354*	.310*	−.136	.423*	−.207	*.771	*1.00		
8. Past participle	.282*	.242*	−.070	.454*	−.283*	.770*	.763*	1.00	
9. Combined past	.391*	.327*	−.097	.435*	−.234*	.822*	.838*	.807*	1.00

*$p < .01$.

matical ratings, and the second highest correlation with the dependent variable, accuracy. So in the remaining analyses only the frequency of all verb forms was used. In the remainder of the article, *frequency* always refers to the total frequency of all of the forms of the verb.

Both inflection form and frequency were entered, stepwise, into multiple regression equations to predict the dependent variables RT, accuracy, and grammatical ratings. Both independent variables entered the equation significantly at the .01 level. The multiple correlations were $r = .575$, for RT, $r = .353$ for accuracy, and $r = .843$ for grammatical rating. The partial correlation between the RT and frequency was –.526, $p < .01$, when inflection form was entered, indicating that when the frequency of the correct form of the misinflected verb is high it takes less time to reject the ungrammatical item. The partial correlation between grammatical rating and frequency was –..538, $p < .01$, indicating that the higher the frequency and hence the higher the familiarity of the irregular form of the verb, the lower the grammaticality rating that its regular form received.

The correlation between frequency and the three dependent variables was also computed for the embedded category. All correlations were significant at the .05 level. The correlations were $r = .913$ for RT, $r = -.895$ for accuracy, and $r = .796$ for grammatical rating.

Notice from Table 2 that the standard deviation of grammatical judgments of very-low-frequency irregular verbs (.88) is more than four times that for high-frequency irregular verbs (.19), but no corresponding differences are observed across frequency levels for regular verbs. There were no very-low-frequency irregular verbs in this experiment, for which there was wide agreement among subjects that the regular form is unacceptable. Furthermore, a further survey of English confirmed that no such low-frequency irregular verbs exist (Bybee, 1985). The nonexistence of very-low-frequency irregular verbs demonstrates that an irregular verb must be heard a certain number of times for the regular form to be perceived as ungrammatical (see also Ullman, 1999).

EXPERIMENT 2

We next used a naming task (Forster & Chambers, 1973) to show that an irregular past tense verb is named more quickly when it follows its own misinflected form. If *thinked* is perceived as ungrammatical because it activates *thought,* then the prime–target pair *thinked/ thought* should produce a shorter naming time for *thought* than an unrelated verb prime (e.g., *ranked/ thought*). Notice that the activation of *thought* by *thinked* must occur within the time frame that *thinked* is perceived as ungrammatical to account for it. The results of Experiment 1 put a bound of less than 2 s on the time to perceive *thinked* as ungrammatical. So *thinked* was directly followed by *thought,* without any intervening items.

For an initial experiment, an experimental list was constructed using 120 misinflected irregular past tense verbs. We then added the 120 correct irregular versions of the misinflected irregular verbs and 120 present tense regular verbs. These were then combined into the following critical sets of prime–target pairs: regular past tense prime with an irregular past tense target (e.g., *ranked/ thought*); and a misinflected irregular prime with the same correct irregular past tense verb (e.g., *thinked/ thought*). Obviously, priming should occur only for the latter set of prime–target pairs. Each subject saw the prime on the screen for 300 ms. After 100 ms, the target came on the screen. The subject read the second word into the microphone as quickly as possible. The results were that an irregular past tense verb was spoken significantly faster when preceded by its own misinflected form (467 ms) than by another verb (519 ms) for all except the very-low-frequency irregular verbs.

In the experiment, except for *goed/ went* the experimental primes (e.g., *thinked/ thought*) always had the same onsets, but this was not necessarily true of the control items (e.g., *ranked/ thought*). It seemed to us that the obvious unacceptability of *goed* indicated that the priming leading to the unacceptability of the regular forms of irregular verbs could not be based solely on form priming because of the shared onset between the forms. Notice that even if the predominant cause of priming between a misinflected irregular verb and its correct form is onset priming, this does not invalidate the hypothesis that this is the cause of the perceived deviance of the misinflected form. Rather, it suggests that phonological priming plays a role in grammatical intuition. Nevertheless, it became of further interest to determine whether the priming in the experiment was purely the result of the same onset between the prime and target or was the result of some more specific and abstract association between the prime and target. So another experiment was done to hold this factor constant. In Experiment 2, the control pairs (e.g., *thanked/ thought*) and the experimental pairs (e.g., *thinked/ thought*) always had the same initial onset. In addition, two kinds of filler items were included. Filler items were created by pairing each prime with a regular verb (*thinked/ walked, thanked/ walked*). Therefore, primes were equally likely to be followed by regular and irregular targets.

METHOD

Subjects

Twelve introductory psychology students who were native speakers of English participated in the experiment to satisfy a class requirement. All subjects had

English as their first language. The subjects were tested individually on the same computer. The number of subjects was dictated by the analysis. Only a simple 2 × 3 design was planned in which both factors were within subjects and one factor (prime type) was within items. Only frequency was necessarily between items. Because 130 items were being used, if the effect was there it was certain to be significant over items, even with only 12 subjects contributing to each item mean. A total of 130 items contributing to each subject mean was more than sufficient to ensure the reliability of the subject data points as well.

Materials

An experimental list was constructed using 130 misinflected irregular past tense verb primes (e.g., *thinked*) and 130 regular past tense verb primes with the same initial consonant cluster (*thanked*). The 130 items comprised all the unambiguously irregular high-, medium-, and low-frequency verbs in English. The regular past tense verb primes were created by changing the initial vowel in the irregular verb to create, wherever possible, a verb in the same frequency range, as defined in Experiment 1. However, as mentioned earlier, it was not possible to match high-frequency irregular verbs with equal-frequency regular verbs. In each case a moderate-frequency verb was constructed. Each prime was paired with an irregular past tense verb to form the experimental (e.g., *thinked/thought*) and control items (e.g., *thanked/thought*) and was paired with a regular past tense verb to form the filler items (e.g., *thinked/thrilled, thanked/thrilled*). The prime and target always had the same initial consonant cluster.

The 130 prime–target pairs of each of the four types were combined into four sublists of 130 items (32 or 33 pairs of each type) such that no prime or target was repeated within a single 130-item sublist. Across the experiment, each prime and target appeared twice, once in each of two different types of items.

Procedure

Items were presented on the screen of a Micro Generation 460 personal computer with the Windows 95 operating system. Each subject saw the prime in lowercase on the screen for 300 ms. After 100 ms, the target in uppercase came on the screen. The subject read the second word into the microphone as quickly as possible. The onset of the subject's response terminated the presentation of the target. Superlab software was used to control stimuli presentation and data collection. After the experiment was completed we received an alert from Superlab that with some personal computers the timing of microphone input was inaccurate. However, before the experiment had been performed a test had been run and the results from Superlab had been indistinguishable from that given by a voice key that was accurate to the millisecond on the computer it was installed in. After the alert a further test was done with auditory signals that were generated at precise intervals as input for the microphone. Again, the timing was accurate to a millisecond.

The experiment began with 20 practice items with verbs that did not appear among the other test items. Each of 12 subjects saw the four sublists in a different order that together made a complete Latin square design. A pause separated the sublists. It was up to the subject to initiate each sublist. No subject took more than a few seconds to do so. Each sublist began with two practice items that the subject was unaware were practiced items. The items within each sublist were presented to each subject in a different random order.

RESULTS AND DISCUSSION

The results are shown in Table 4. The data were analyzed using a 2 (past tense prime same as target vs. past tense prime different from target) × 3 (frequency levels) repeated measures ANOVA that resulted in a significant effect of prime–target pair type for subjects, $F(1, 11) = 5.6$, $p < .05$, and items, $F(1, 129) = 11$, $p < .001$, but no other significant effects. The quasi-F was $F'(1, 25) = 3.71$, $p < .1$. The main effect of prime–target pair demonstrates that a misinflected irregular verb activates its correct form, even when onset priming is controlled.

EXPERIMENT 3

The fact that priming was observed even when onset was controlled for suggests that it occurred at a more abstract level than form priming. Specifically, the effect was consistent with either lexical or sublexical priming between *feel* and *felt* that also produced priming between *feeled* and *felt.* A purely lexical effect would result from *feel, feeled,* and *felt* all activating the same logogen. In this case, there would be no reason to expect the priming from *feeled* to *felt* to be any greater than the priming from *feel* to *felt* because it relies on the fact that *feeled* contains *feel.* In fact, it might be the case that the priming of *feeled* to *felt* would be less than the priming of *feel* to *felt* because it required first parsing *feel* from the nonword *feeled.* Also, there would be no reason for *feeled* to prime *dealt,* which of course is a separate word with a separate logogen. A sublexical effect would result from *feeled* activating the specific representation of the past tense of *feel,* which included the representation of *felt.* This hypothesis is called sublexical because it assumes that

Table 4. Mean response time (and standard deviation) in ms to read verbs in Experiment 2

	Irregular verb targets		Filler regular verb targets	
Frequency*	Irregular verb prime	Regular verb prime	Irregular verb prime	Regular verb prime
High	506 (64)	513 (59)	530 (70)	539 (68)
Moderate	501 (69)	515 (66)	523 (68)	520 (62)
Low	498 (68)	510 (62)	526 (72)	522 (67)

*Of irregular verb targets.

the phonological representations of the different forms of the verb are formed by combining a common onset with different rimes. Onsets and rimes are sublexical units. In this case, the priming from *feeled* to *felt* might be greater than the priming of *feel* to *felt* because the *-ed* context would be an additional cue for the past tense, which would independently help activate it. Also, it would be possible for *feeled* to prime dealt through the pathway *feeled–felt–dealt* if *felt* and *dealt* shared a common representation of the rime used to construct their past tenses.

The final experiment examined the sublexical priming hypothesis by testing whether there was neighborhood priming between *dealt* and *felt.* So if *feeled* primes *dealt,* then it should speed the acceptance of *dealt* and the rejection of *dealed* when compared with the prime *wheeled.* A priming experiment was performed in which subjects had to indicate whether the target was grammatical. Both regular and irregular primes were paired with grammatical targets (e.g., *wheeled/ dealt* vs. *feeled/ dealt*) and ungrammatical targets (e.g., *wheeled/ dealed* vs. *feeled/ dealed*). To ensure that subjects would not simply respond "grammatical" or "ungrammatical" on the basis of the target's inflection control, items were added with ungrammatical irregular inflections (e.g., *winked/ appealt*) and grammatical regular inflections (e.g., *winked/ appealed*). Unfortunately, this design required the inclusion of nonwords (e.g., *appealt*) that seemed to confuse the subjects. The error rate for these items was 30% and for the critical items was 15%. As predicted, the targets with the irregular primes (e.g., *feeled/ dealt, feeled/ dealed*) were responded to faster than the targets with the regular primes (e.g., *wheeled/ dealt, wheeled/ dealed*). However, even though the overall effect was significant, when tested by contrasts the difference reached significance only for the grammatical targets. So 20 new subjects were run in a replication of the four critical conditions, in addition to 32 filler items with regular verbs to ensure that subjects would not respond "no" to a target whenever it had a regular inflection. The results of the simpler design are reported here.

METHOD

Subjects

Twenty Rutgers University undergraduates who were native speakers of English participated for credit in general psychology. The subjects were tested individually on the same computer. The number of subjects was dictated by the analysis. Only a simple 2 × 2 repeated-measures design was planned. Within this design, the extensive previous experience of the experimenter indicated that a minimum of 16 items and 16 subjects was needed to obtain significance over both subjects and items when the effect was there. Slight overscheduling of subjects to account for no-shows actually produced 20 subjects.

Materials

First, 32 irregular verbs were selected, and "regularized" misinflected forms were created. These items, both grammatical and ungrammatical, are called targets because these are the items that the subject judged. Each target, grammatical (irregular past tense) and ungrammatical (misinflected irregular past tense), was paired with a prime that was either a rhyming regular past tense verb, hence morphologically different from the target, or a misinflected irregular past tense verb that was morphologically related to the target. These items are called primes because they preceded the targets in the experiment. An example of each prime–target pair is shown in Table 5.

Each target version (grammatical versus ungrammatical) was paired with each prime version (regular, hence morphologically different, vs. irregular and morphologically related), resulting in the creation of 128 pairs. Therefore, there were 32 pairs of each type shown in Table 5. In addition, 16 pairs of filler items (e.g., *killed/molded*) were included to ensure that subjects would not respond "no" to a target whenever it had a regular inflection.

The resulting 160 word pairs (including fillers) were divided into two sublists of 80 pairs each so that subjects could be given a pause to rest in the middle of the experiment. Finally, a separate list of 16 pairs in which all primes were grammatical regular forms and targets were either grammatical irregular forms or ungrammatical regularized versions was created for use in a practice session. All the verbs used in the experiment had frequency greater than 10 and less than 1,000 per million (i.e., low to moderate frequencies).

Procedure

A short prime–target stimulus onset asynchrony (SOA) of 400 ms was specifically chosen to preclude the use of predictive strategies by subjects. Neely (1977) found no effect of an expectation at this SOA. For each trial, a fixation cross (+) appeared in the center of the screen for 5 s, then the prime appeared in lowercase for 400 ms, immediately followed by the target in uppercase. Subjects indicated with a key press whether or not the word was grammatical. The key press terminated the presentation of the target. MEL software was used to control stimuli presentation and data collection.

Half the subjects used the "j" key if the probe was deemed "grammatical," and the remaining half used the "f" key. Each subject first completed 16 practice trials with items that contained verbs that were not among the test items.

Table 5. Mean (and standard deviation) of RT and error rates for critical items of Experiment 3

	Prime					
Target	Regular item	Mean RT	Error (%)	Irregular item	Mean RT	Error (%)
Grammatical	*wheeled/dealt*	1,348 (723)	8 (5)	*feeled/dealt*	1,131 (390)	5 (2)
Ungrammatical	*wheeled/dealed*	1,768 (791)	9 (6)	*feeled/dealed*	1,491 (691)	6 (1)

Note. RT = response time.

Half the subjects saw one sublist first, and half saw the other sublist first, with a pause between them. Order of presentation of pairs within sublists was random, and the order of the two lists was counterbalanced across subjects.

RESULTS AND DISCUSSION

The results can be seen in Table 5. For RT there were significant main effects of target, $F'(1, 48) = 29.0$, $p < .01$, and prime, $F'(1, 50) = 8.1$, $p < .01$, but no significant interaction. Newman–Keuls tests, $p < .05$, revealed that both grammatical verb targets (e.g., *feeled/ dealt*) and ungrammatical verb targets (e.g., *feeled/ dealed*) were accepted faster when preceded by a related prime than an unrelated prime (e.g., *wheeled/ dealt, wheeled/ dealed*). Differences between error rates were not significant.

GENERAL DISCUSSION

The overall results of these experiments are consistent with the hypothesis that a misinflected verb is perceived as unacceptable because it activates its correct form. First, we found that both the time to reject a misinflected irregular verb and intuitions of its relative acceptability are related to the frequency of the correct irregular verb. Second, presenting a misinflected form such as *thinked* reduces the time to name the correct form of the same verb (i.e., *thought*). Finally, that *feeled* primes *dealt,* the past form of a morphologically related verb, implies that it also primes *felt.*

Our results suggest that these effects involve lexical and morphological elements beyond phonological and other form features. In Experiments 2 and 3 the control primes (e.g., *thanked, wheeled*) shared exactly the same degree of phonological and visual similarity to the targets (e.g., *thought, dealt*) as the experimental primes (e.g., *thinked, feeled*). Nevertheless, RT was shorter in the experimental conditions.

These results are well accounted for by the sublexical priming hypothesis. According to this hypothesis, a word consists of sublexical units just as a sentence consists of words. A word's representation may be retrieved, or it may be constructed by assembling sublexical units in sequence, just as a sentence is constructed by assembling words in sequence. The advantage of retrieval is the speed of processing of familiar items. The advantage of construction is the ability to process novel inputs by assembling familiar units into new sequences that have specific meanings. Whenever a representation is assembled, we call the assembly procedures rules. However, we can use rules to construct words with the meanings of words that already exist. In this case, the meaning activates the alternative, more familiar word, so that the novel word is perceived as deviant.

Figure 1 illustrates a version of the sublexical priming hypothesis. The figure is obviously not a complete representation of the lexicon but the minimal number of nodes necessary to illustrate the hypothesis. Three kinds of nodes are shown. The rectangles are lexical nodes. The hexagons are sublexical nodes that encode phonological regularities among words. Therefore, in the figure, the rhyming present tense verbs *feel, deal, wheel,* and *appeal* share a common node and the rhyming past tense verbs *felt* and *dealt* share a common node because they contain the same rime. The circles represent the unique sets of semantic and syntactic features that distinguish each lexical item. Each lexical item accesses a unique set of semantic features (S1, S2, S3, and S4) and either the present tense node (P^0) or the past tense node (P^-). The arrow from P^- to P^0 is inhibitory. So if both the present and past nodes are activated by a lexical item, only P^- remains active.

Notice that all other arrows are bidirectional. A lexical node may be activated in two ways. First, it may be activated by an input external to the figure. Second, it is activated if one directly associated semantic node and one directly associated syntactic node are activated. Through the second route *felt* is activated by *feeled,* as was suggested by the results of Experiment 1 and confirmed by the results of Experiment 2. Also, the

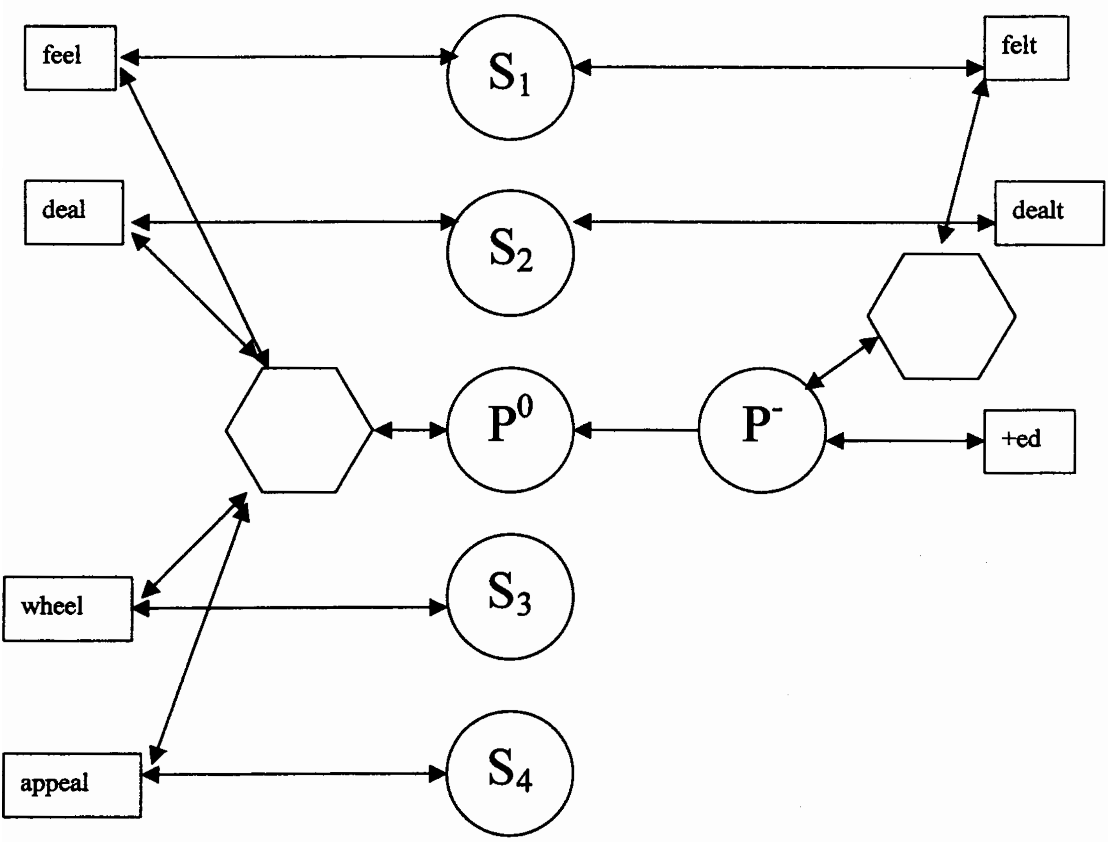

Figure 1. Illustration of the sublexical priming hypothesis

sublexical node shared by *felt* and *dealt* causes *dealt* as well as *felt* to be primed by *feeled*, as was confirmed in Experiment 3, although only *felt* is activated, enters awareness, and contributes to the perceived deviance of *feeled*. However, there is no node for *feeled*, which is why it is perceived as novel, which also contributes to its perceived deviance.

This hypothesis shares similarities with both the unique entry principle and connectionist accounts of inflection. As mentioned earlier, the hypothesis may be considered an elaboration of the unique entry principle. The unique entry principle is that a specific rule blocks a more general rule. In fact, recently, Pinker (1999) has revised and renamed the unique entry principle as the blocking principle. According to the blocking principle, a stored form blocks the application of a rule. Blocking is not inconsistent with priming. Indeed, it requires it because only if the stored form is primed (or retrieved) can it do the blocking. The blocking and priming hypotheses are quite similar. The one difference is that blocking, like unique entry, is merely a post hoc restatement of the effect when irregular forms and rules conflict, rather than an explanatory principle. In contrast, the priming hypothesis is explanatory. The perceived deviance of *comed* is the direct consequence of its perceived novelty in the context of the perceived familiarity of *came*. Listeners are educated to classify as deviant a novel form that primes a familiar form that may be substituted for it.

Blocking and priming also provide different explanations when we turn from perception to production. The blocking hypothesis exists in the context of rule-driven theories of language production that have to explain why *comed* is not produced. The explanation is that this rule-generated form primes *came*, which blocks it. The priming hypothesis exists in the context of a retrieval-driven theory of language production that makes use of rules only to generate forms that cannot be retrieved from memory. Within the context of this theory, because *comed* has not been heard, it is not produced. So there is nothing to explain.

The priming hypothesis is that the rule-generated lexical form also activates the irregular lexical form, and it is for this reason that it is perceived as deviant. This makes our results least consistent with the model of Rumelhart and McClelland (1986). More recently, there have been a number of refinements of the Rumelhart–McClelland model, such as Cottrell and Plunkett (1994), MacWhinney and Leinbach (1991), Plaut (1997), and Plunkett and Marchman (1993), which take account of the role of morphology and have sublexical (or hidden) nodes. These models can explain the results of Experiments 1 and 2. However, these networks do not have nodes corresponding to the *felt/dealt* sublexical node and therefore do not predict the observed priming between *feeled* and *dealt*. So this result presents a new challenge to these models.

Also, the proposed *felt/dealt* sublexical node was not an ad hoc construction but was predicted by Fowler et al.'s (1985) hypothesis that the lexicon encodes sublexical regularities. Although the present study has examined only the role of priming in the perceptions of the past inflection for verbs, it seems probable to us that the same results could be obtained for nouns and adjectives. For nouns, the regular plural (e.g., *mans, mouses*) sounds unacceptable when there is a high-frequency irregular form (*men, mice*). For adjectives (e.g., *large, pretty*), they can become comparatives or superlatives by either taking an inflection (e.g., *larger, prettier*) or by combining with an adverb (e.g., *more large, more pretty*), the former being the most common. Presumably the unacceptability of the adverbial form comes from the fact that the higher-frequency inflected form is accessed. Notice that both the adverbial and inflected form of moderate- and low-frequency adjectives (e.g., *scanty, grumpy*) are acceptable because neither is frequent, hence familiar, enough to cause the other form to be perceived as odd. Furthermore, the adverbial form is acceptable with all adjectives that, for phonological reasons, do not have inflected comparative forms (e.g., *more intelligent, most intense*). So the priming hypothesis may have applications beyond the present study.

Finally, the sublexical priming explanation for the perceived deviance of a regularized irregular verb is consistent with explanations of other cases of perceived deviance. The general explanation is that something is perceived as deviant when the novel perceptual representation constructed for it activates and brings to awareness a different familiar representation stored in memory. For example, the standard localist explanation for why the pronunciation of *dog* as /dahg/ is perceived as deviant is that it activates the correct pronunciation /dawg/. Word recognition appears to be governed by parallel sublexical and lexical pathways. For regularly pronounced words (e.g., *barn, darn, mint, hint, gave save, bog, fog*), both pathways produce the same representation. However, for irregularly pronounced words (e.g., *warn, pint, have, dog*) the pathways activate different representations. The conflicting information from the two pathways must be resolved before the word can be pronounced. So skilled readers are slower to pronounce irregularly pronounced words than regularly pronounced words (Rastle & Coltheart, 1999).

A similar explanation applies to the detection of false statements. People know that "A bird has arms" is false because the statement activates and brings to awareness the contradictory fact that a bird has wings. Therefore, the associative strength of the contradiction or counterexample, which predicts its speed of access, is also correlated with the time to reject the false statement (Holyoak & Glass, 1975). Of course there are differences between knowing that /dahg/ is a mispronunciation because it brings to mind /dawg/, knowing that *feeled* is a misinflection because it brings to mind *felt,* and knowing that birds have arms is a misstatement because it brings to mind wings. However, there are also similarities between these explanations. Within this framework, the unacceptability of *feeled* is not the result of a narrow syntactic principle but a general aspect of cognitive processing. Words are typically not presented in isolation but within contexts. When the word or its context activates a competing word for that context, the presented word may appear wrong, deviant, or unacceptable, depending on the task and the context.

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