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Irregularization: The Interaction of Item Frequency and Phonological Interference in Regular Past Tense Production

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Abstract

Both dual mechanism and connectionist single mechanism accounts predict that phonologically similar irregulars can interfere with regular past tense production. In dual mechanism accounts, such interference depends on irregular frequency but not on the frequency of regulars with the possible exception of high frequency regulars. Such models predict that high and low frequency regulars are equally susceptible to interference from irregulars, or that high frequency regulars would be more affected than low frequency ones. Connectionist single mechanism models, on the other hand, claim that low frequency regulars are more susceptible to interference from irregulars than high frequency regulars. We present results from two experiments that investigate interference from irregulars on the past tense production of high and low frequency regular verbs. In these experiments, high frequency regulars were less affected by interference from phonologically similar irregulars than low frequency regulars. These results support connectionist single mechanism models of past tense verb production.

The dichotomy between regular and irregular patterns permeates many levels of language. In many areas, accounting for differences between regular and irregular patterns has become the battlefield on which competing theories of language processing win or lose. One such case, which has received much attention in recent years, is the production of the past tense form of English verbs. This case has become the focus of an ongoing debate between dual mechanism and connectionist single mechanism models of word processing (MacWhinney B. & Leinbach, J., 1991; Marchman et al., 1999; Marcus, 1995a, 1995b, 1996; Pinker 1991, 1999; Pinker & Prince, 1991, Plunket & Marchman, 1993, 1996; Rumlehart & McClelland, 1986; Seidenberg 1997).

Dual Mechanism Accounts. In dual mechanism accounts (Marcus, 1995a, 1995b, 1996; Pinker 1991, 1999; Pinker & Prince, 1991), regular past tense is produced via a rule (add *–ed*) that applies to the root stem of the verb, which is stored in the mental lexicon. Irregulars, on the other hand, are formed via associations between present and past tense forms, each of which is stored as a separate lexical entry. The add *–ed* rule applies as a default to verbs without a separate lexical past tense entry (regulars and non-words). The existence of a separate past tense entry, as in the case of irregulars, blocks the application of the add *–ed* rule. However, if the representation of a past tense entry is weak (due to low frequency), the add *–ed* rule could be applied erroneously, causing an over-regularization error (buy > *buyed). Such errors are well documented both under natural and experimental conditions (Berko, 1958; Bybee & Slobin, 1982; Marcus et al., 1992). In addition to irregulars being regularized, regulars can also be incorrectly produced as if they were irregulars (e.g., vie > *vought). This phenomenon of "irregularization" has also been documented both in and out of the laboratory (Bybee and Moder, 1983; Xu & Pinker, 1995).

Pinker (1999), in his most recent version of a dual mechanism model, provides an account of irregularization. In his model, the word association mechanism responsible for irregular past tense production is a connectionist type neural network that contains both *irregular* and *high frequency regular* items. In the course of past tense production, the network attempts to compose a past tense form on the basis of the present tense. Phonological overlap between regular and irregular items can cause two types of interference during this computation. First, an incorrect form may gain enough activation to actually block the add *–ed* rule resulting in an irregularization error. Alternatively, regular past tense production could be successful, but the spurious activation caused by interference may slow down production.

By this account, interference (and past tense production) is generally insensitive to the frequency of regular verbs. One exception may result from the encoding of regular past tense forms of high frequency regular verbs in the associative network. The encoding of these past tense forms in the network can sometimes cause high frequency regulars to be more affected by interference from irregulars than low frequency regulars:

> "As mentioned in note 11, sometimes high-frequency regular verbs are, paradoxically, *slower* to produce than low-frequency verbs. One explanation is that stored forms always inhibit the rule, even if they are identical to the form the rule is trying to create. Just as *broke* blocks the creation of *breaked* an entry for *walked* that is stored in memory may block the creation of *walked* by rule, slowing down the rule production (compared to, say, *stalked*, whose memory entry is too weak to slow down the rule)."
>
> (Pinker, 1999, page 303, fn 22)

Connectionist single mechanism Accounts. Connectionist single mechanism models rely on a single mechanism to account for both regular and irregular past tense production (MacWhinney, B. & Leinbach, J., 1991; Marchman, Wulfeck, & Weismer,1999; Plunket & Marchman, 1993, 1996; Rumlehart & McClelland, 1986; Seidenberg 1997). The claim is that both regulars and irregulars are represented in a single neural network. The network encodes mappings between present and past tenses as weighted links between forms. More exposure to a particular mapping strengthens the corresponding link. In this way, the strength of mappings for both regular and irregular items is determined by item frequency and the consistency of the present to past tense mapping within the neighborhood of phonologically similar verbs.

In this model, interference on regular and irregular past production is the result of a single mechanism. As activation spreads and a past tense form (regular or irregular) is being selected, interference from overlapping mappings (regular or irregular) can cause interference. In past tense production, a target form must reach a critical activation level before it is selected. In order for this to happen, activation of competing forms must be suppressed. If a competing form is not suppressed and its activation exceeds that of the correct form and reaches a critical threshold, an irregularization error occurs. However, even if correct selection is eventually successful, the activation of competing forms may cause the system to take longer to settle on the correct form and may thus result in slowed production. In this account, due to the greater strength of their mappings, high frequency regular and irregular verbs are less susceptible to interference from other items than low frequency verbs. Thus, the connectionist single mechanism account and the dual mechanism account both predict the same two types of possible interference: (1) irregularization errors, and (2) slowing of correct production. However, the two accounts differ in their prediction of how interference will affect high and low frequency regulars. The dual mechanism account predicts that interference should result in more errors and slower production for high frequency regular verbs than for low frequency regular verbs. The connectionist single mechanism account, on the other hand, predicts more errors and slowed production for the low frequency regulars than for the high frequency regulars. The following experiments tested these contrasting predictions.

Experiment 1

This experiment investigated the effects of interference from irregulars on regular past tense production. More specifically, we tested the degree to which high and low frequency regulars are differentially affected by such interference.

One potential problem facing an investigation of this type is the subtle nature of interference effects from irregulars. In order to get around this problem, we designed the experiment so as to enhance the interfering effects of irregulars. According to both models, phonological overlap can yield irregularization errors and slowed production. We reasoned that one possible way to enhance the effect of phonological similarity is to make this similarity more salient by having participants produce the past tense form of an irregular verb (e.g., *buy*) immediately prior to producing the past tense form of a phonologically similar regular verb (e.g., *die*). This was done for both high and low frequency regulars creating the two interference conditions shown in Table 1. We decided on an all auditory presentation of stimuli and responses so as to further enhance the (possibly interfering) effect of phonological similarity. We also had a control condition in which the same regular verbs were preceded by non-similar irregulars, creating the two control conditions shown in Table 1. Thus, the complete design was 2 X 2 with factors Frequency (high vs. low) and Context (interference vs. control).

Table 1: Experiment 1 Conditions. Shown is the regular target (**in bold**) with the irregular from the preceding trial.

	Context	
Frequency	Interference	Control
High	Buy **Die**	Hear **Die**
Low	Buy **Vie**	Hear **Vie**

Both models predict that the interference condition will be slower and more error prone than the control for both high and low frequency regulars. However, the two models differ in their predictions for the interaction between context and frequency. The dual mechanism model claims that the difference between the interference and control conditions will either be equal for both high and low frequency regulars, or perhaps be greater for high than low frequency regulars. According to Pinker (1999), high frequency regulars should be more susceptible to interference when the experimental list includes a high proportion of irregular verbs, as in the present experiment (50%):

> "… the harmful effects of high frequency tend to occur when the word list has a high percentage of irregular forms, encouraging subjects to go to their mental lexicons on every trial…"
>
> (Pinker, 1999, pp. 303, f. 22)

The connectionist single mechanism account, on the other hand, predicts that the difference between the interference and control conditions will be greater for the low frequency regulars than for the high frequency regulars.

Method

Participants. 61 undergraduate students from the Department of Psychology at the University of Southern California received extra credit to participate in the experiment. All were native speakers of English.

Materials. 20 Monosyllabic English irregular present tense verbs were matched with 20 phonologically similar monosyllabic high frequency (Mean frequency 185) and 20 phonologically similar monosyllabic low frequency (Mean frequency 3) present tense regular verbs creating 20 *high interference pairs* and 20 *low interference pairs*. The same set of items was then regrouped such that each irregular verb was matched with a non-similar sounding high and low frequency regular verb creating 20 *high control pairs* and 20 *low control pairs*. Verb frequencies were taken from the Francis & Kucera (1982) corpus.

To ensure that each participant responded to each regular item only once, the prime and control pairs were divided into four lists (1A/1B, 2A/2B) each containing one-quarter of the experimental pairs with the number, type, and frequency of pairs balanced across lists. 23 regular and 44 irregular monosyllabic present tense verbs were selected as fillers to balance the appearance of regular and irregular items on the four lists. The lists were ordered in a pseudo-random fashion. Presentation of lists was balanced across participants.

A practice list was also created consisting of 10 regular and 10 irregular present tense verbs that were not included in the experimental lists.

All items were read by a male native speaker of English and digitally recorded in 16 bit 20 MHZ format. Individual words were later excised using a digital sound manipulation program.

Procedure. Stimuli were presented to participants through headphones at 2000 ms intervals using the PsyScope program (Cohen, J., MacWhinney, B., Flatt, M., & Provost, J., 1993). Participants were instructed to say the past tense form of the verb they heard. In order to encourage rapid responses and reduce possible strategy effects, participants were instructed to say the past tense as quickly as possible. If participants didn't answer within a 1500ms interval, they were signaled with a beep. Responses were coded as either 'correct', 'incorrect' or 'equipment error'. All participants received the same 20-item practice list before being tested on one of the two A/B list sets. Order of presentation of the lists was alternated giving a total of four potential presentation patterns (1a>1b, 1b>1a, 2a>2b, 2b>2a) that were counterbalanced across participants. There was a short break between the lists. The total testing time was approximately 30 min. Participant responses were recorded. Recordings were used to verify initial coding of responses and to transcribe and code responses for the error analysis.

Results

Data were included only for responses to regular targets that followed the correct production of the preceding irregular item. Responses to regulars that followed an incorrect irregular were not included because in such cases it is not clear whether participants had processed the preceding irregular. Six participants (4% of data) and three items (2% of data) had to be removed from the analyses due to insufficient data contribution. Initial analyses of list order effects indicated that there was no interaction between list presentation order and any of the conditions of the experiment. Thus, the data from initial and second presentations were collapsed.

Error analysis. Responses were classified as follows:

(1) *Correct*: the regular past tense form was correctly produced.

(2) *Irregularization Error*: the regular past tense form was incorrect and the form of the error had a direct relationship to an existing past tense irregular form. (e.g., the past tense of 'vie' produced as 'vought').

(3) *Miscellaneous Error*: the regular past tense form was incorrect and the form of the error did not relate to an existing irregular past tense form (e.g., vie > died).

Table 3 shows the distribution (raw numbers and percentages) of response types in the different conditions.

Table 3: Response types in Experiment 1

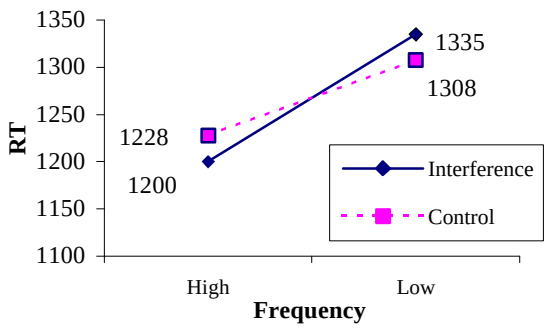
	Context	
Response Type	Interference	Control
	High	
Correct	344 (95%)	349 (96%)
Irregularization Error	7 (2%)	3 (1%)
Misc. Error	13 (4%)	10 (3%)
	Low	
Correct	256 (88%)	273 (91%)
Irregularization Error	13 (4%)	4 (1%)
Misc. Error	20 (7%)	22 (7%)
	Total	
Correct	600 (92%)	622 (94%)
Irregularization Error	20 (3%)	7 (1%)
Misc. Error	33 (5%)	32 (5%)

To assess the effect of frequency and context on response type we conducted a log-linear analysis on these responses starting with the maximal model – Context (interference vs. control) x Frequency (high vs. low) x Response Type (correct vs. irregularization error vs. miscellaneous error). The only terms that are of potential interest here are the interaction terms that included the response type and that were crucial for the model's fit. The

terms that met these criteria in this experiment were the term expressing the interaction between context and response type (LR $\chi^2(2)=7.03$, $p<.0297$) and the term expressing the interaction between frequency and response type (LR $\chi^2(2)=15.17$, $p<.0005$). The three-way interaction between context, frequency and response type was not significant (LR $\chi^2(2)=.7698$). Thus, while both context and frequency had an effect on response type, these effects were independent of each other. Participants made more errors with the low frequency verbs than with the high frequency verbs but this frequency effect was comparable in the interference and control conditions. To better examine the distribution of the different response types in the interference and control conditions, we combined the responses from the high and low frequency conditions (as in the bottom part of Table 3). While in both prime and control conditions there is an equal percentage of miscellaneous errors (5%), the prime condition has more irregularization errors (5%) than the control condition (3%). This difference proved to be significant according to a chi-square test including correct responses in the analysis ($\chi^2(1)=6.47$, $p<.0394$), as well as an analysis of the error data alone ($\chi^2(1)=6.62$, $p<.0364$).

Latencies. Figure 1 shows RTs for correct responses in all four conditions. While low frequency regulars were produced slower in the interference than in the control condition, high frequency regulars were actually produced faster in the interference condition. An ANOVA with factors Frequency (high vs. low) and Context (interference vs. control) revealed a main effect of frequency whereby participants took significantly longer to produce the past tense form of low frequency regular verbs compared to high frequency ones (1322 ms vs.1214 ms), $F_1(1, 54)=111$, $p<.001$, $F_2(1, 35)=7.244$, $p<.01$. Context had no main effect, F_1, $F_2<1$. The interaction between context and frequency was significant by participants, $F_1(1, 54)=4.095$, $p<.048$, although not by items, $F_2<1$.

Figure 1: RT Experiment 1



Discussion

Consistent with the predictions of both the dual mechanism and the connectionist single mechanism accounts, interference from a similar sounding irregular was found to increase the likelihood of making an irregularization error in producing the past tense form of regular verbs. However, the error data show that, in contrast to the claims of Pinker's (1999) dual mechanism account, the production of low frequency regulars is overall more prone to errors than the production of high frequency regulars. Nevertheless, the error data did not provide strong support for the connectionist single mechanism account because high and low frequency regulars were affected equally in both the control and interference condition. This failure to detect a significant effect may be a reflection of a true lack of interaction, as the dual mechanism model may predict, or it may simply be a result of a lack of power due to the subtlety of the effect and low cell count (participants produced very few errors overall.) A more informative measure of performance that is not prone to the small cell size problem and its associated low power was provided by response latencies in correct regular past tense production.

The analysis of response latencies revealed, as in the error data analysis, a general advantage for high frequency regulars such that they were faster than low frequency regulars. Importantly, this finding precludes a speed accuracy trade-off explanation of the error data. There are two aspects of these results, however, that need to be dealt with before any further interpretation of the latency data can be made. First, the past tense form of high frequency verbs was produced faster in the interference condition than in the control condition, in contrast to the predictions of both models. Second, the fact that the interaction between frequency and context was significant only in the by-participants analysis but not in the by-items analysis suggests that items varied in some important aspect that we may have overlooked. One such aspect may be related to priming effects between the present tense forms, independent of the production of the past tense. To perform the task, participants had to, first, process the present tense form of each verb, and, second, generate the past tense form. Thus, response times in this task indicate not only the time it took participants to generate past tense forms but also the time it took them to process the present tense forms. It may be that phonological similarity, which caused interference in the production of the past tense form, facilitated the processing of the present tense form. The high frequency regulars may have thus elicited faster responses in the interference condition because, for these verbs, phonological similarity benefited the processing of the present tense forms more than it interfered with the production of the past tense forms. For the low frequency regulars, on the other hand, phonological similarity may have interfered with the production of the past tense forms more than it benefited the processing of the present tense forms. Differences between items in the relative strengths of the benefit and the interference associated with phonological similarity may also help explain the differences between the by-participants and by-items analyses. It is important to note here that this interpretation only applies for the specific irregular/regular pairs as used in

this experimental manipulation and not for regular verbs in general. In order to test this interpretation, it is necessary to confirm the facilitatory effects of phonological similarity on the processing of the present tense in the interference condition and then reanalyze the data taking these effects into account. Experiment 2 was undertaken to directly measure the effect of phonological similarity on the processing of the present forms.

Experiment 2

This experiment was identical to Experiment 1 in materials and procedure but employed a repetition task instead of past tense generation. Thus, in Experiment 2, the interference condition of Experiment 1 became a priming condition in which the preceding phonologically similar irregular could prime the recognition of the regular target item.

Method

Participants. 25 undergraduate students (different from Experiment 1) from the Department of Psychology at the University of Southern California received extra credit to participate in the experiment. All were native speakers of English

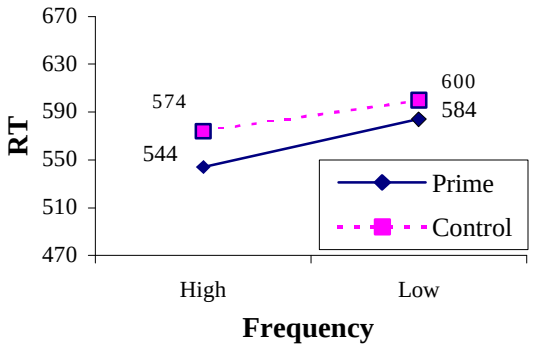
Materials. Same as in Experiment 1.

Procedure. Same as in Experiment 1 except that participants were instructed to repeat the verb that they heard rather than produce the past tense. The presentation interval was reduced to 650 ms and the time-out interval to 600 ms.

Results

As with Experiment 1, only responses to regular verbs that followed the correct repetition of the preceding irregular verb were included. 3 subjects (5% of data) and 4 items (7% of data) were excluded from the analysis due to insufficient data contributions. Mean RTs are shown in Figure 2. An ANOVA with factors Frequency (high vs. low) and Context (prime vs. control) revealed a main effect of frequency whereby high frequency verbs were repeated faster than low frequency verbs (558 ms vs. 591 ms), $F_1(1, 21)=39.59$, $p<.0001$, $F_2(1, 34)=3.923$, $p<0.056$. There was also a main effect of context whereby participants were faster at repeating target items in the prime condition than in the control condition, (564 ms vs. 592 ms), $F_1(1, 21)=7.062$, $p<.015$, $F_2(1, 34)=6.062$, $p<0.019$. There was no interaction between context and frequency, F_1, $F_2<1$.

Figure 2: RT Experiment 2



Discussion

The fact that both high and low frequency regulars were repeated faster in the prime condition confirms the claim that the interference condition of Experiment 1 also involved facilitation of the initial processing of the present tense. Furthermore, the lack of context by frequency interaction in Experiment 2 suggests that the context by frequency interaction observed in Experiment 1 was not related to the processing of the present tenses but was only related to the generation of the past tense. Most importantly, however, the results of Experiment 2 can be used to reanalyze the results of Experiment 1 while factoring out the priming effects related to the processing of the present forms.

Combined Experiment 1 and 2 Analyses. One possible way to factor out the effects of present tense priming is by repeating the by-items analysis of Experiment 1 with Experiment 2 response times as covariates. Due to differences in the magnitude and variability of response times in the two experiments, response times were log transformed (Emerson, 1991). An ANCOVA of the log transformed RTs in Experiment 1, with factors Frequency (high vs. low), Context (interference vs. control), and covariates Prime and Control Log RTs from Experiment 2, found no main effect for context, $F<1$, a marginally significant main effect of frequency, $F(1,32)=3.391$, $p<.075$, and finally, a significant interaction between context and frequency, $F(1, 32)=4.176$, $p<.049$. Thus, a by-items analysis in which the processing of present tenses was controlled for, found, as did the original by-participants analysis, a significant interaction between context and frequency.

To further explore the nature of this interaction we calculated the partial correlation between the interference on each item in Experiment 1 (RT in interference condition minus RT in control condition) and their frequency (log transformed) while controlling for the item's priming in Experiment 2 (RT in prime condition minus RT in control condition). This analysis found that item frequency and the extent of interference for that item were negatively correlated ($r= -0.35$, $p<.037$) such that the higher the item frequency, the less was the effect of interference.

Discussion of Combined Analyses

The reanalysis of Experiment 1 showed that once the effects of processing the present tense were factored out, the item analysis corroborated the participant analysis in showing a

significant interaction between interference and frequency. Importantly, this analysis revealed that low frequency regulars were affected by interference more than high frequency regulars. This finding is squarely incompatible with Pinker's (1999) dual mechanism account.

General Discussion and Conclusions

Two production experiments tested the extent to which irregular verbs could interfere with the past tense production of regular verbs. Irregularization errors were more likely when regular verbs were preceded by phonologically similar irregulars than when they were preceded by phonologically dissimilar irregulars. Furthermore, overall production errors were more likely for low frequency regular verbs than for high frequency regular verbs. Finally, an analysis of latencies of correct responses showed that, once the effects of processing the present tenses are controlled for, high frequency regulars are more immune than low frequency regulars to interference from phonologically similar irregulars.

These findings are incompatible with the prediction of Pinker's *Words and Rules* dual mechanism model (Pinker, 1999) that high frequency regulars should be affected by interference more than low frequency regulars. One obvious way in which Pinker's model could be modified to account for our findings is by simply changing it to say that regular past tense production could benefit (rather than be hindered) by the existence of a form in the associative network. While such modification may help account for the current findings, it is not clear what its other consequences may be.

Clearly, frequency effects are not the only relevant evidence for understanding the mechanisms underlying past tense production. Thus, the present findings should not be viewed as the ultimate proof that the connectionist approach is right and that the dual mechanism account is wrong. Rather, the present findings should be viewed as adding one piece to a growing body of evidence that suggests that the separation of language processing into two mechanisms is buying less and less in terms of explanatory power but costing more and more in terms of unnecessary theoretical baggage.

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