



Brief article

Past tense route priming

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ABSTRACT

The present research examined whether lexical (whole word) or more rule-based (morphological constituent) processes can be locally biased by experimental list context in past tense verb inflection. In Experiment 1, younger and older adults completed a past tense inflection task in which list context was manipulated across blocks containing regular past tense verbs (e.g. REACH-REACHED) or irregular past tense verbs (TEACH-TAUGHT). Critical targets, consisting of half regular and half irregular verbs, were embedded within blocks and participants' inflection response latency and accuracy were assessed. The results yielded a cross-over interaction in response latencies for both young and older adults. In the regular context there was a robust regularity effect: regular target verbs were conjugated faster than irregular target verbs. In contrast, in the irregular context, irregular target verbs were conjugated faster than regular target verbs. Experiment 2 used the same targets but in the context of either standard nonwords or nonwords ending in “-ED” to test the possibility of a phonological basis for the effect. The effect of context was eliminated. The results support the notion that distinct processes in past tense verb production can be locally biased by list context and, as shown in Experiment 2, this route priming effect was not due to phonological priming.

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1. Introduction

An overarching goal of psycholinguists is to identify the specialization of language systems (e.g., modules) to handle different input types (e.g., Fodor, 2008). The current study examines the extent to which basic linguistic processes are flexibly influenced by local context-specific control systems, as has been observed in other cognitive domains such as attention and memory.

One area where the flexibility of the language processor has been recently explored is in speeded word naming, a quasi regular domain in English where there are both regular (e.g., HINT) and irregular (e.g., PINT) mappings of spelling-to-sound correspondence (e.g., Kinoshita, Lupker, & Rastle, 2004; Monsell, Patterson, Graham, Hughes, &

Milroy, 1992; Reynolds & Besner, 2008; Zevin & Balota, 2000). For example, Zevin and Balota (2000) asked participants to read aloud a series of context items and target words. The context items consisted of either low-frequency exception words (biasing a more lexical/whole word processing) or nonwords (biasing a more sublexical mapping of spelling-to-sound conversion). Zevin and Balota found that nonword primes, relative to low-frequency exception word primes, produced a higher proportion of regularization errors (mistakenly pronouncing an exception word according to spelling-to-sound rules, as in “pint” rhyming with “mint”), and a larger regularity effect. Within a dual route model of word pronunciation (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), these results suggest that lexical or sublexical processing pathways can be biased by local context, and points to the need for a more flexible model of the lexical processing system.

Although the pronunciation studies are suggestive of flexible language processing, one may question whether the pattern observed in word pronunciation extends to

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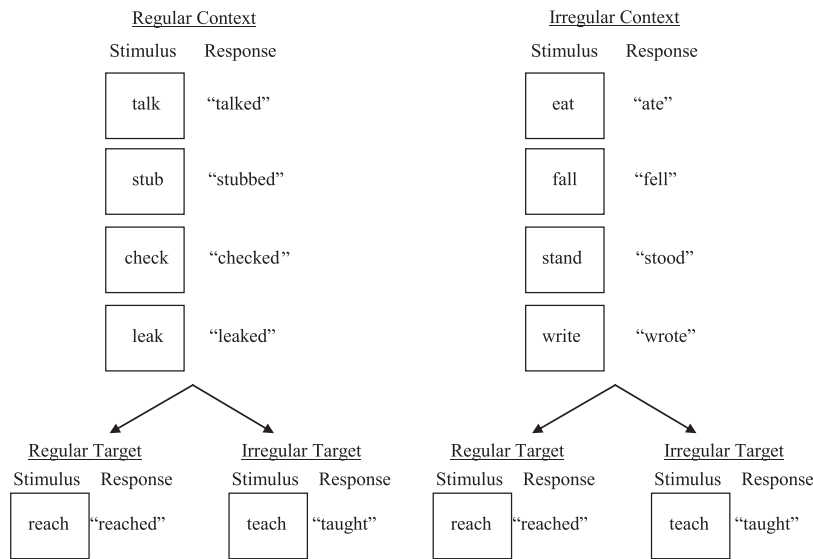


Fig. 1. Regular and irregular list contexts for the regular target word "Reach" and the irregular target word "Teach".

more central components of language processing. Moreover, as discussed below, there are alternative accounts of the pronunciation results (see for example, Kinoshita & Lupker, 2002). Therefore, the present study explores whether such flexibility can be observed in another quasi-regular domain in English, past tense verb production.

A dual-route model of past tense inflection (as in Pinker and Ullman (2002)), posits two pathways by which one can produce a past tense form of a verb from the present tense form.¹ The first route is through the "word" pathway, in which the full lexical form of the present-tense target is matched against an entry in the mental lexicon, and the corresponding past tense entry is accessed directly. The second route is through the "rule" pathway, in which the present-tense target is stripped down to its constituent stem and one of three past tense allomorphs (/d/, /t/, or /ɪd/) is added to produce the correct phonological form. In this way, the "word" and "rule" pathways are analogous to the lexical and sublexical pathways in similar dual-route word reading models.

As shown in Fig. 1, in the present study, a rule-based pathway was experimentally biased using verbs that are inflected regularly in the past tense (i.e., the rule of attaching "-ed" to the stripped stem generates the correct output REACH-REACHED). The "words" pathway was biased using verbs that are inflected irregularly in the past tense (i.e., the past tense form is irregular and requires more direct access to its lexical form to produce the correct output,

TEACH-TAUGHT). Pathway processing was assessed via performance on either regular or irregular verbs, which were embedded within blocks that biased either the rule based pathway or the whole word pathway. If the pathway priming observed in speeded pronunciation extends to past tense verb generation, then performance should be faster and more accurate for targets that are congruent with the contexts (e.g., reach-reached in a regular block), relative to targets that are incongruent with the contexts (e.g., teach-taught in a regular block).

In addition to extending the previous work with younger adults, we also examined such pathway control in an older group of participants. Language is a compelling domain in which to study aging, since older adults often have intact language processing systems even though there are changes in tasks that require controlled attention (Hasher & Zacks, 1988). The relative stability of language processing in older adults is also observed in the present study and so the major contribution of including these participants is a replication of the basic pattern across the adult age range.

2. Method

2.1. Participants

Younger adult subjects ($N = 37$, Mean age = 19 years, $SD = 1.3$) were undergraduates at Washington University, whereas, older adult subjects ($N = 44$, Mean age = 74 years, $SD = 7.2$) were community-dwelling participants. Younger adults chose between course credit and monetary compensation (\$10), and older adults were offered monetary compensation (\$10). All subjects were native English speakers and did not self-report any significant vision or hearing problems. Younger adults had fewer years of education on average ($M = 13$ years, $SD = 1.1$) than older adults ($M = 16$ years, $SD = 2.7$), $t(76) = 5.10$, $p < .001$.

¹ The current study uses a dual-route perspective to frame this research, however, it is important to acknowledge that there are alternative approaches to past tense conjugation (for example see Rumelhart et al., 1986, for a connectionist model of past tense inflection; Albright & Hayes, 2003, for a fully rule-based model of past tense inflection). Moreover, for simplicity sake we are treating regularity as a single dimension, while there are likely differing degrees of regularity (for example, see Seidenberg & Bruck, 1990, as discussed in Seidenberg (1992), for a description of consistency as an alternative; and also Kielar, Joanisse, & Hare, 2008, for a graded account of regularity).

2.2. Stimuli

The context words consisted of 93 regular and 93 irregular verbs (see Appendix A), and targets consisted of 20 regular and 20 irregular verbs (see Appendix B). For both context words and targets, regular and irregular verbs were matched on length in letters, HAL word frequency (Lund & Burgess, 1996), and orthographic and phonological Levenshtein distance (Yarkoni, Balota, & Yap, 2008), all $p > .12$ (see Table 1). All verbs used as stimuli had only one acceptable past tense form. Four lists were constructed for counterbalancing purposes; each list contained critical target items with 3–7 intervening context words. Across lists, each target was seen in both contexts, but no word was seen more than once per participant.

2.3. Procedure

Each trial consisted of the following sequence of events: (a) a 500-ms fixation point (three asterisks), (b) a blank screen for 250 ms, (c) a present-tense verb which remained onscreen until a vocal response was detected, (d) the experimenter coded the response, and (e) a 500-ms inter-trial interval consisting of a blank screen. Participants were not informed about the contextual manipulation and were simply asked to name the past tense of each verb aloud as quickly and as accurately as possible. Responses were coded as correct, incorrect, microphone error/dysfluency, or regularization error (e.g., “TEACHED instead of “TAUGHT”). Participants were presented with a practice block of eight trials, followed by two test blocks with a rest break in between. The experimental blocks consisted of 113 trials, with 93 context trials and 20 target trials. Context type (regular vs. irregular) order was counterbalanced across participants.

2.4. Results

RTs under 200 ms or over 3000 ms were first trimmed, and then any observation 3 standard deviations from each participant’s mean was also trimmed. The overall percentage of trials trimmed was 1.5%.

Table 1
Stimuli characteristics.

	Primes (N = 186)		Targets (N = 40)	
	Regular	Irregular	Regular	Irregular
Length in Letters	5.26 (.17)	5.09 (.18)	5.10 (.20)	4.9 (.15)
Log HAL Frequency	8.31 (.28)	8.91 (.27)	9.63 (.34)	9.73 (.33)
Orthographic LD	1.79 (.06)	1.77 (.07)	1.74 (.07)	1.64 (.04)
Phonological LD	1.62 (.07)	1.65 (.08)	1.51 (.08)	1.46 (.06)

Note: Standard errors of the mean are in parentheses. *Log Hal frequency* is the log of the Hyperspace Analogue to Language frequency (Lund & Burgess, 1996). *Orthographic LD* and *Phonological LD* are measures of orthographic and phonological Levenshtein distance, (Yarkoni et al., 2008).

Analyses were conducted on both the participant-level (F_1) and the item-level means (F_2). For each analysis, we conducted a 2 (Context Type: regular vs. irregular verb) by 2 (Target Type: regular vs. irregular verb) by 2 (Age: younger vs. older adults) mixed effects analysis of variance (ANOVA) on mean RT, z-scored RT, and proportion correct. We also conducted a one-way repeated measures ANOVA with two levels (young vs. older adults) on the regularization errors for irregular verbs. z-Scores were used in order to compare younger and older adults, because the z-transform puts each participant’s trial-level data on the same scale and therefore controls for general slowing effects in RT across age groups (see Faust, Balota, Spieler, & Ferraro, 1999). Additionally, the accuracy and regularization errors variables were subject to an arcsine transformation to more closely approximate a normal distribution (Winer, 1971).

2.5. Prime trials

Although the emphasis will be on the target data, it is worth noting that as expected performance was overall faster on regular context verbs (863 ms in subject-level means, 890 in item-level means) than on irregular context verbs (1028 ms in subject-level means, 1120 in item-level means), $t_1(79) = 9.5$, $p < .001$, $t_2(184) = 10.0$, $p < .001$. Accuracy was also higher on regular (.96 correct) than on irregular context verbs (.83 correct), $t_1(79) = 12.5$, $p < .001$, $t_2(184) = 7.6$, $p < .001$. This pattern occurred in both young and older adults, and did not interact with age in the z-score analyses that controls for scaling differences.

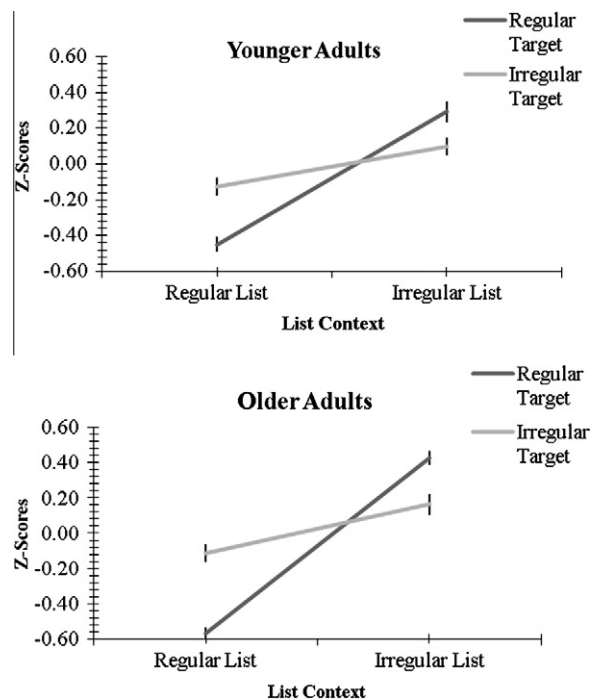


Fig. 2. Mean standardized response latencies as a function of age, list context, and target type. Error bars represent standard error of the mean.

2.6. Target response latencies

As shown in Fig. 2, there are main effects of Target Type, $F_1(1,76) = 6.38$, $MSE = 73,309$, $p = .014$, $F_2(1,76) = 2.62$, $MSE = 58,828$, $p = .168$, and Context Type, $F_1(1,78) = 125.71$, $MSE = 2,778,587$, $p < .001$, $F_2(1,76) = 158.28$, $MSE = 1,269,956$, $p < .001$. Importantly, there is a cross over interaction between the two variables, $F_1(1,78) = 77.43$, $MSE = 822,089$, $p < .001$, $F_2(1,76) = 52.05$, $MSE = 417,627$, $p < .001$. This interaction occurs for both young and older adults, when analyzed separately, and Age did not modulate this pattern in the z-score analyses.

2.7. Target accuracy and regularization errors

As shown in Fig. 3, for accuracy, there was a main effect of Target Type, $F_1(1,78) = 212.113$, $MSE = 31.05$, $p < .001$, $F_2(1,76) = 55.68$, $MSE = 12.73$, $p < .001$, and a Target Type \times Context Type interaction, $F_1(1,78) = 22.94$, $MSE = 2.79$, $p < .001$, $F_2(1,76) = 19.44$, $MSE = 1.71$, $p < .001$. This interaction reflects the larger difference between regular

and irregular targets in the regular list context (.21) than in the irregular list context (.11).

For regularization errors (e.g., producing EATED to EAT), there was a main effect of context type, $F_1(1,78) = 30.20$, $MSE = 3.81$, $p < .001$, $F_2(1,38) = 13.42$, $MSE = 1.45$, $p = .001$, indicating that there were more regularization errors in the regular context (.06) than the irregular context (.14). There was a main effect of age in the subject-level analyses, $F_1(1,78) = 8.98$, $MSE = 1.93$, $p = .004$, that did not reach significance in the item level analysis, $F_2(1,19) = .614$, $MSE = .24$, $p = .44$. This age effect reflects relatively higher regularization error rates for the younger adults (.13) than the older adults (.08).

In sum, the target data displayed a powerful crossover interaction of past tense route priming. In the regular context, the past tenses of regular verbs were produced more quickly than irregular verbs, whereas, in the irregular context, the past tenses of irregular verbs were produced more quickly than regular verbs.

2.8. Discussion

The crossover interaction in Experiment 1 supports the flexibility of the processes engaged in past tense verb inflection. However, before turning to a discussion of the implications of the current results, it is important to consider an alternative hypothesis, which Experiment 2 was designed to assess.

3. Experiment 2

It is possible that the observed context effect at least for the regular verbs involves a type of phonological priming. Specifically, it is possible that participants were simply biased to produce responses with an “-ed” at the end in the regular context, independent of any morphological processing. This would facilitate the processing of regular words, and interfere with the processing of irregular verbs. To directly address the role of phonological priming the same targets were embedded within context blocks that included a set of standard nonwords (e.g., BANDOP) or a set of nonwords (e.g., BANTED) ending in “-ed.” Participants conjugated the interspersed target verbs (as in Experiment 1), but *read* the context nonwords aloud. Hence, one can examine the contribution of a phonological effect influencing the pattern in Experiment 1, without any morphological pathway processing. The assumption here is that these nonwords were unlikely to be processed as nonword + stem, and hence, were unlikely to engage the past tense pathway. If phonological priming underlies the effects observed in Experiment 1, then one should find facilitation for the regular verbs, compared to irregular verbs following “-ed” nonwords compared to non “-ed” nonwords.

3.1. Participants

Participants ($N = 26$) were recruited from the same undergraduate pool used in Experiment 1.

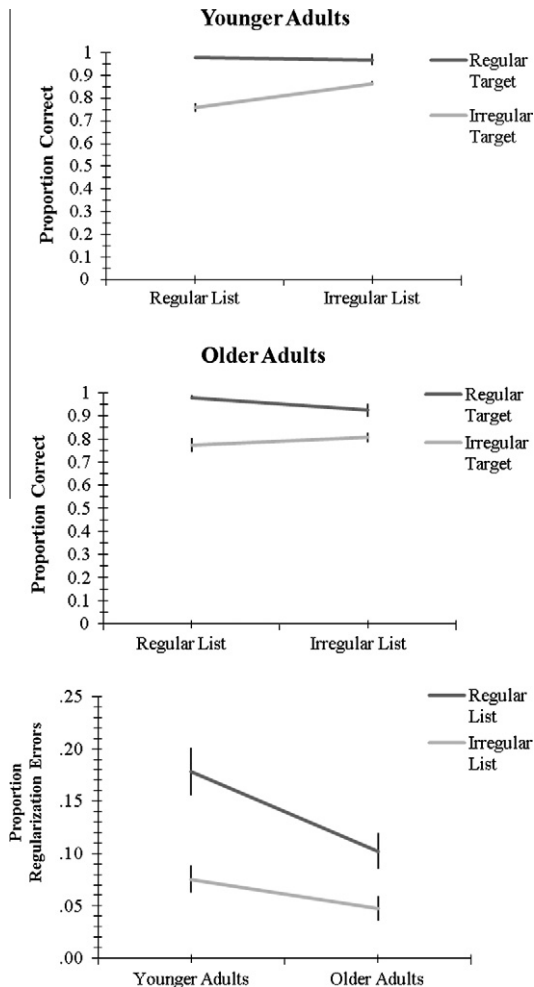


Fig. 3. Mean proportion of total errors (not including microphone errors) and regularization errors as a function of age, list context, and target type. Error bars represent standard error of the mean.

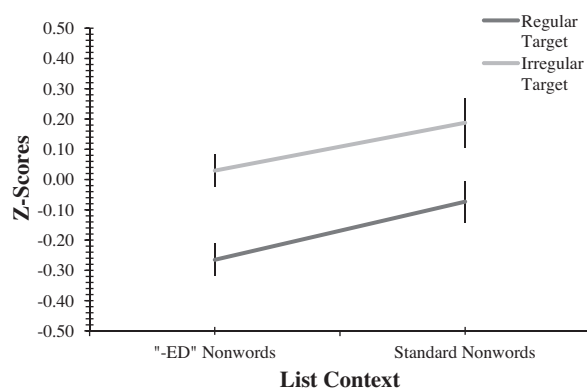


Fig. 4. Mean standardized response latencies as a function of list context and target type. Error bars represent standard error of the mean.

3.2. Stimuli

Target items consisted of the same set of stimuli used in Experiment 1. Context items either consisted of standard nonwords (e.g., BLASP, HICE, SAMPER) or nonwords with “-ed” endings (e.g., SILED, GRED, LERTED), see Appendix C. There was no significant difference in length in letters between the two sets, $p > .05$.

3.3. Procedure

The Procedure for Experiment 2 was identical to Experiment 1 (see Fig. 1), except that participants were asked to read the nonwords aloud, and generate the past tense of the present tense target verbs. Nonword primes were presented in white and present-tense target verbs in red.

3.4. Results

The RT results (see Fig. 4) yielded a main effect of Context Type, $F_1(1,25) = 4.22$, $MSE = 37,491$, $p = .05$, $F_2(1,38) = 13.52$, $MSE = 47,484$, $p = .001$, and Target Type, $F_1(1,25) = 16.02$, $MSE = 82,406$, $p < .001$, $F_2(1,38) = 7.44$, $MSE = 78,437$, $p = .01$. Importantly, there was no hint of a Context Type \times Target Type interaction, $F_1(1,25) = .208$, $MSE = 824$, $p = .65$, $F_2(1,25) = 1.79$, $MSE = 6273$, $p = 189$.

The accuracy analyses yielded no effect of Context type, $F_1(1,25) = 1.21$, $MSE = .012$, $p = .28$, $F_2(1,38) = .69$, $MSE = .005$, $p = .41$, a main effect of Target type, $F_1(1,25) = 22.62$, $MSE = .695$, $p < .001$, $F_2(1,25) = 10.21$, $MSE = .24$, $p = .003$, with no evidence of an interaction, $F_1(1,25) = .207$, $p = .65$, $F_2(1,38) = .23$, $MSE = .002$, $p = .63$.

3.5. Discussion

The results from Experiment 2 provided no evidence that the regularity effect is modulated by phonological repetition of “-ed” allomorphs for nonwords. Thus, phonological biasing due to adding “-ed” to verbs to produce the past tense does not appear to underlie the observed biasing in past tense verb generation with real verbs found in Experiment 1.

4. General discussion

The results of Experiment 1 provide strong support for the flexibility of the processes engaged in past tense verb inflection. Specifically, regular verbs were processed more quickly than irregular verbs in a more rule-pathway biasing context, whereas irregular verbs were processed more quickly than regular verbs in a more whole word pathway biasing context. The ability of a contextual manipulation to have an influence on performance demonstrates strategic adjustment of past tense processing pathways based upon the local list context. Remarkably, there was a full crossover interaction in the response latency data. Moreover, the percentage of regularization errors (e.g., TEACHED) was also higher in the regular context than in the irregular context, a finding predicted by route priming, since the regular context should bias “-ED” endings more strongly than the irregular context. The results from Experiment 2 indicate that phonological priming was not underlying the observed pattern of results.

It is important to note that the present results cannot be accommodated by a simple time criterion model, in which difficulty of the context trials can carry over into target processing, i.e., targets will speed up when embedded within other fast trials, and slow down when embedded in slow trials. Specifically, although never completely dismissing the attentional control hypothesis, Lupker, Brown, and Colombo (1997) and Kinoshita and Lupker (2002) have used the time criterion hypothesis as an alternative explanation of the pronunciation route priming results that have been taken as supportive of the attentional control hypothesis. However, in the present study, the complete crossover in the regularity effect across the list contexts cannot be accommodated by a time criterion model. Indeed, even if overall prime speed is partialled out, the critical interaction between Target Type and Context Type in response latencies remains highly reliable, $F(1,75) = 30.64$, $MSE = 415,552$, $p < .001$.

At a theoretical level, we have interpreted the present results within a dual-route type model, in which participants are locally biased by either more lexically-driven processing vs. more rule-driven processing, as in the Pinker (1998) Words-and-Rules model. The crossover interaction suggests considerable flexibility in attending to the two different routes, i.e., attention being directed to the word pathway for the irregular list context and the rules pathway in the irregular list context.

At first glance the cross-over interaction appears to be problematic for an unembellished single-route model. We believe such an argument would be premature. For example, it is possible that a triangle architecture, which involves a phonological mapping between present tense and past tense (see Rumelhart, McClelland, & The PDP Research Group, 1986, as hypothesized in Seidenberg & McClelland, 1989), along with an additional source of input to phonological output units from semantics, may also accommodate the present results. This allows information to travel from the orthography to phonology, as well as through semantics to phonology. As Zevin and Balota (2000) argued, if the relative contributions of the different

word mappings (direct from orthographic to phonological vs. semantically mediated) were influenced by the list context, such architectures may also be able to account for route priming results in word pronunciation. Theoretically, a similar implementation of additional sources of information may work for past tense word production models. Independent of theoretical orientation, the present results point to the importance of control systems that modulate the contributions of distinct sources of linguistic information.

It is noteworthy that the present route priming results are much more powerful than the word pronunciation results in producing a complete cross-over interaction. It is possible that the pathways (or sources of information) may be more distinct in past tense formation, such that each pathway can be more completely biased by context. This may reflect a vestige of early acquisition of irregular forms of verbs in which children must make this distinction across different types of verbs (e.g., TEACHED vs. TAUGHT). The current study also used a more demanding task which involved generation of the output instead of the relatively simple pronunciation of words. This more effortful generation process may have contributed to the relatively stronger interaction observed.

In summary, the current study provides the first evidence for route priming in a linguistic domain other than visual word pronunciation. Ultimately, the results support the notion of a flexible lexical processor, because individuals rely on distinct processes tied to the past tense production of regular and irregular verbs (see Balota & Yap, 2006). This work highlights the need to consider how and when context can bias the contributions of distinct processing pathways in linguistic performance.

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Appendix A

Irregular target verbs

arise
awake
begin
bring
creep
deal
draw
fall
fling
give
grow
hurt
shrink
speak

spend
split
stand
strike
sweep
thrust

Regular target verbs

approve
assert
charge
check
crease
cube
force
gain
guide
jump
lack
print
quote
scroll
solve
stay
stitch
stub
thrill
track

Appendix B

Experiment 1 – Regular context verbs

ail	gorge	purport
amass	help	quiet
back	hitch	reap
blight	impart	recant
buffet	inoculate	reduce
capture	invest	repeat
change	jab	resonate
clot	laud	retreat
clump	leaf	rip
coerce	list	rouse
combine	loot	route
coo	mail	seat
corner	mesh	sensitize
deign	moor	service
deplore	nab	shovel
devise	need	skim
dimple	occur	slave
dip	open	sponge
dissect	own	spout
dissipate	partition	start
drill	pelt	steer
droop	pick	subsist
duck	place	taste
dupe	play	terrify

Appendix C (continued)

darпка	plomeg
deapol	pluce
dedeg	podet
dermol	replee
donil	rolpeeg
dringe	romuk
dubeen	sainet
feaple	samper
fiпод	sape
gechoy	semmel
giep	sewk
gleet	siley
grel	soptil
hape	spo
heakel	stedek
heg	sule
hetel	teap
hice	tenny
hoch	trok
hoive	twal
huple	wape
irp	woft
jeel	yerty
	yomeg
	yuke

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