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Past Tense Route Priming

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Abstract

The current study 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 younger and older adults. During each trial, participants produced the past tense verb from a present tense verb. List context was manipulated across blocks such that context trials consisted of either regular past tense verbs (e.g., LIVE-LIVED) or irregular past tense verbs (e.g., RUN-RAN). Half of the targets within each list context were regular and half were irregular verbs. In the regular context, there was a very robust regularity effect: regular targets verbs were conjugated faster and more accurately than irregular target verbs. In the irregular context, this regularity effect was reversed in response times and diminished in accuracy. Age group and individual difference measures of attention and vocabulary were also investigated as possible variables that may modulate the route priming effects. The results support the notion that distinct processes in past tense verb production can be locally biased by list context.

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Note. All error bars represent standard error of the mean (SEM)

Past Tense Route Priming

An overarching goal of psycholinguists is to understand the structures involved in basic language processing. In pursuit of this goal, most research consists of experiments designed to uncover the underlying structure of different linguistic systems. The typical theoretical approach is to assume modularity within the language system, or in other words, specialization of language systems to handle different input types. As outlined by Fodor (2008), a modular input system is domain-specific and "informationally encapsulated" (i.e., bottom-up in nature and having little access to central or attentional control systems). Fodor further specified that these input systems are fast-acting, mandatorily engaged by the nature of the input, and barely, if at all, accessible by consciousness. The current study examines the assumptions that systems are controlled by the nature of the input, and that there is very little influence on output processes from the higher-order systems involved in attentional control. The suggestion here is that the "uncovering-architecture" approach lacks consideration of the flexible nature of the linguistic system, an alternative outlined by Balota, Paul, and Spieler (1999).

The static, modular approach described above is exemplified in single- and dual-route models of language. Single-route approaches were first proposed by Chomsky (1965), in his theory of generative linguistics. Specifically, Chomsky proposed that fully explicit rules exist and dictate the input-to-output journey in linguistic processes. Researchers in this tradition proposed domain-specific transformational grammar rules in order to describe a linguistic process. For example, the process of getting from the present to the past tense in English is represented by the rule: "process present tense verb, strip it down to its stem, and add the past tense affix /Id/, /t/, or /d/." Chomsky argued that similar rules could be used in other domains of language processing, such as the translation between orthography and phonology, or spelling to sound. Attempts to fully characterize these relationships as rules were unsuccessful, however, and Chomsky's approach has been mostly replaced by the somewhat less rule-based models discussed below.

These newer accounts typically fall into one of two camps: dual-route or connectionist models (though recently there have been hybrid models, see Albright and Hayes, 2003, for past tense verb production and CDP++, Perry, Ziegler, & Zorzi, 2007, 2010, for spelling to sound translation). Although the current study is in the domain of past tense inflection, these models are first considered with respect to how they account for the process of translating an orthographic code to a phonological code, or reading words aloud. The process of reading aloud is discussed because it has been by far the most widely-studied context for the dual-route versus connectionist debate, and the current experiment naturally extends work that has already been conducted in word naming.

Dual-route theorists, such as Coltheart and colleagues (beginning with Coltheart, 1978, but more recently Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001, & Perry, Ziegler, & Zorzi, 2007, 2010), suggest that language processing occurs along two distinct pathways. The *sublexical pathway* is a bottom-up, rule-based construction process which converts orthographic patterns into phonological patterns based on spelling to sound correspondence rules. In contrast, the *lexical* pathway is more memory-based and consists of a pattern-matching or "lookup" process in the mental dictionary. These pathways have differing defining characteristics because of their inherent architectural dissimilarities. For example, in Coltheart et al.'s (2001) dual-route model of word reading, the lexical route is more sensitive to word frequency, whereas the sublexical route is more sensitive to word length. Route-specific features such as these can account for simple effects such as the word frequency effect (the finding that the higher the frequency of the word, the more quickly it is pronounced) and the lexicality effect (the finding that words, which can be accessed relatively quickly via the lexical pathway, are read aloud more quickly than nonwords, which necessitate accessing the slower spelling-to-sound correspondence rules). Furthermore, the multiple pathway perspective quite easily accommodates the complex finding of a regularity by frequency interaction, which refers to the finding that the difference between regular (e.g., hall) and exception (e.g., chaos) words is much larger for low-frequency words than high-frequency words. This is explained in dual-route terms by assuming that high frequency words are accessed so quickly via the lexical pathway that even for the exception words, competing output from the sublexical route isn't available quickly enough to influence the motor response of reading aloud. However, for low-frequency words, access to pronunciation via the lexical pathway is much slower; hence, the sublexical pathway competes for output for irregular words (e.g., the incorrect /pInt/ instead of /paInt/). It is this output competition that particularly slows the pronunciation response for low-frequency exception words.

Turning to the single-route connectionist perspective (Rumelhart, McClelland, & the PDP Research Group, 1986, and McClelland, Rumelhart, & the PDP Research Group, 1986), this approach has been developed for nearly every process involved in language comprehension and production. In contrast to dual-route models, connectionist models contain no explicit rules, and instead, they contain networks of basic linguistic units, or nodes, that are interconnected via links through which activation spreads. Over training, these networks use feedback to adjust their pattern of activation via learning principles which gradually approach the correct response. Connectionist models rely on graded statistical patterns rather than on explicit rules or dichotomous regularity, though they can still explain many of the same effects as dual-route models because of how they are trained. Training of the network is based on the frequency of occurrence of a word in the language (i.e., as the frequency of a word increases, the likelihood of it being selected for model training also increases). Units that often co-activate develop stronger connection weights and smaller error scores. The constituents in high-frequency words have been co-activated more often relative to the constituents in lower-frequency words, and the constituents in both high- and low-frequency words have been co-activated more often relative to nonwords (which are essentially words with no frequency of occurrence), thus the model can display both frequency and lexicality effects.

Connectionist models also appear to accommodate more complex patterns such as the regularity by frequency interaction (see Seidenberg and McClelland, 1989). Although connectionist networks *can* simulate regularity effects, they typically eschew the concept of regularity in favor of a related, and highly overlapping, variable known as consistency. Consistency is a continuous measure of how similar in pronunciation a word is to its orthographic neighbors. For words higher in frequency, the influence of neighborhood consistency is lessened, because those words are highly trained. The result is that the model shows something very similar to a regularity by frequency interaction: there is a less of a difference between high- and low-consistency words at high frequency of occurrence, and a more pronounced consistency effect at lower frequencies of occurrence.

Both dual-route and connectionist approaches attempt to describe the structural aspects of the language system in a relatively modular fashion, impenetrable by controlled attention. However, our use of language both in and outside of an experimental setting is not free from the impact of attentional control and pre-existing and experimenter-manipulated biases. The apparent flexibility of the lexical system has been the focus of several visual word recognition studies.

In one study, Monsell, Patterson, Graham, Hughes, and Milroy (1992) compared reaction time and proportion correct in a pure-block condition, in which participants pronounced only nonwords (e.g., flirp or mofarch) or low frequency exception words (e.g. pint or castle), relative to a mixed-block condition, in which participants pronounced nonwords and low frequency exception words intermixed with one another. The hypothesis that readers have control over lexical processing would lead one to expect attention to be differentially allocated in the pure and mixed blocks. More specifically, readers should be able to increase proportion correct and decrease response latencies in pure blocks (in which they are able to strategically rely on one pathway) relative to mixed blocks (in which they cannot do so). In support of predictions made with the flexibility of the lexical system in mind, Monsell et al. found that participants were faster and more accurate in the pure-block conditions, compared to the mixed-block condition. This finding was attributed to participants' ability to allocate attention to the most appropriate pathway. Low-frequency exception words presumably directed attention to the lexical pathway, since they contain irregular pronunciations that can only be arrived at correctly by directly accessing a lexical entry in memory. Nonwords, on the other hand, presumably directed attention to the sublexical pathway because they can only be successfully read aloud by applying the spelling-to-sound correspondence principles—words that have never before been encountered could not possibly be in the mental lexicon. In contrast to the pure-block condition, participants in the mixed condition could not direct attention to one of these pathways because both were relevant across trials. Reynolds and Besner (2005) also provided support for a pathway control perspective in a paradigm that contained only mixed blocks. They reported a slowdown in reaction time on a "switch" trial (naming a nonword, then low frequency exception word, or vice versa) compared to a "stay" trial (naming a nonword or low frequency exception word twice in a row). Their finding of local switch costs was taken as evidence that participants had to switch processing between lexical and sublexical pathways across trials.

Another study that examined the role of attentional control using was reported by Zevin and Balota (2000). In this study, participants were asked to read aloud four primes followed by a target. Importantly, these primes consisted of either low-frequency exception words or nonwords, and the targets were words or nonwords that depended on the particular experiment (for example, low-frequency regular and low-frequency exception words when the regularity effect was under examination in Experiment 2). Zevin and Balota found that using nonword primes resulted in target performance that aligned closely with what one would predict if the sublexical pathway were biased: a higher proportion of regularization errors (mistakenly pronouncing an exception word according to spelling-to-sound rules, as in "pint" rhyming with "mint"), a larger regularity effect, a smaller frequency effect, and an elimination of the imageability effect, relative to when the lexical pathway was biased. The finding that lexical or sublexical processing pathways can be biased by a preceding set of primes is quite consistent with the idea that controlled attention can bias processing along a pathway.

It should be noted here that there is an alternative hypothesis for these route priming studies; the time criterion account (Taylor & Lupker, 2001) stipulates that it is the speed of the prime trials rather than the type of prime that affects the latency of the target trial. Specifically, pronouncing several fast primes results in the adoption of a fast time criterion, and pronouncing several slow primes results in the adoption of a slow time criterion across all trials. This response deadline affects not only primes, but the embedded targets as well. A time criterion account does not explain the Zevin and Balota (2000) results because their prime stimuli did not differ on overall latency, but is relevant to the current study because of the existence of baseline differences in speed between the regular and irregular verb primes. This account will be addressed in more depth in the discussion.

In summary, a critical issue raised by Balota et al. (1999) is that pathway use in lexical processing is modulated by control of attention and that the theoretical assumption of static, modular language processing systems may not be as straightforward as initially proposed in single- and dual-route approaches. Evidence consistent with this claim has been reported in word reading tasks, but the role of attention in biasing pathway use is not necessarily exclusive to that domain. Balota et al. also pointed out that adopting a processing pathway approach to word reading helps to elucidate some of the conflicting findings that may have resulted from a failure to consider the set of specific performance rules a task introduces (as an example, the effects of word frequency and length are greatly modulated when the dependent measure is lexical decision—word vs. nonword decisions— as opposed to speeded word naming). In order to examine the attentional control hypothesis in other linguistic domains, the Zevin and Balota route priming paradigm was adapted for past tense inflection. Results consistent with the attentional control of processing pathways in past tense inflection would provide converging evidence regarding the flexibility of the lexical processor, in a domain not previously studied in this fashion.

Models of Past Tense Inflection

Turning now to models of past tense inflection, there are again dual-route and connectionist (single-route) approaches. The dual-route model of past tense verb inflection is the Words-and-Rules (WAR) theory (Pinker & Ullman, 2002). In this theory, there are two pathways by which one can produce a past tense form of a verb from the present tense form. 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 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 /*Id*/) 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.

The WAR model stands in contrast to a connectionist model of past tense inflection such as Rumelhart and McClelland's (1986) model. Similar to the connectionist model of word reading discussed above, no explicit rules exist for past tense inflection. Rule-like performance is approximated through a distributed network of pattern detectors linked by connections that change weights as they gain language experience. Through training, the network of pattern detectors captures statistical regularities among verb families, including regular verbs (*walked, talked, locked)* and sub-regular verbs (*swept, kept, leapt)*. The network consists at first of random association weights between input and output units, which are adjusted for optimal performance as the model is exposed to correct present-past tense verb pairs. Eventually the model approximates human performance for past tense inflection. Although the manipulations and results of the current study do not directly refute a connectionist explanation, they are more difficult to accommodate in this rule-free perspective. More importantly, none of the extant models of past tense inflection afford any attentional control system that may bias the relative contributions of more rule-based versus lexically-based processing.

The current study investigated the role of attentional control in modulating the processing pathways of past tense inflection. Like the studies in the domain of word naming, the current study uses the terminology of dual-route models for the purpose of parsimony. However, it is possible to accommodate route priming findings in a single-route connectionist framework; this will be further elaborated in the discussion.

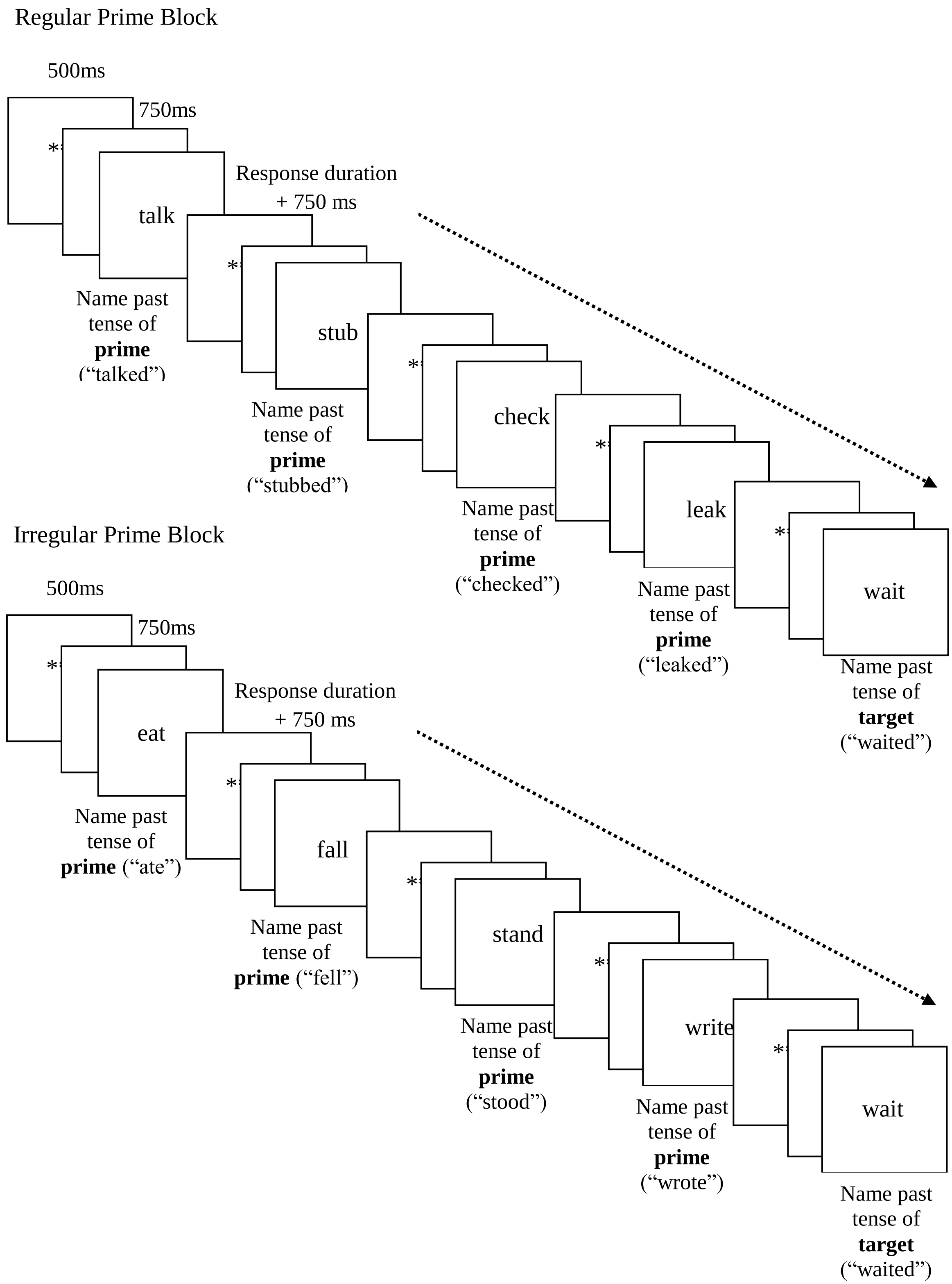
This study focuses on a particular process, that of past tense verb inflection, but is concerned not only with the details of the past tense, but also with the broader issues of the processing that information undergoes on its way to output, the flexible nature of this path, and its similarity and relation to other domains of language processing.

The current study used a procedure similar to that used by Zevin and Balota (2000). As shown in Figure 1, the Zevin and Balota word-naming paradigm was adapted such that participants were asked to conjugate each present tense verb into the past tense. The 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 will generate the correct output TALK-TALKED). The lexical, or "words" pathway was biased using verbs that are inflected irregularly in the past tense (i.e., the past tense form is irregular and must be directly addressed to produce the correct output, RUN-RAN). Prime type was blocked and manipulated within-participants, such that participants completed one block in which all primes were regular verbs and one block in which all primes were irregular verbs. Pathway processing was assessed in terms of reaction time and proportion correct to target verbs, which appeared embedded within both prime blocks. If pathway priming extends to past tense verb generation, then performance should be faster and more accurate for targets that are congruent with the primes (e.g., walk-walked in a regular block), relative to targets that are incongruent with the primes (e.g., run-ran in a regular block).

Aging and Attentional Control of Processing Pathways

In addition to investigating the role of attention in pathway control, the present study will examine these control systems in both healthy younger and older adults. With the exception of some unpublished data from Balota, Yap, and Coane (2008) investigating route priming in word naming, the route priming phenomenon has not been explored with older adults. Language is a compelling domain in which to study aging. On one hand, older adults are expert communicators with at least four additional decades of experience with language compared to their younger counterparts. On the other hand, there is evidence that older adults have difficulty with tasks that require

Figure 1. The experimental paradigm



controlled attention and inhibition of task-irrelevant or extraneous information (Hasher & Zacks, 1988). Thus, there are several interesting predictions related to older adults' performance in the current study. First, if older adults have breakdowns in attentional control then one might a priori expect more difficulty controlling the primed pathway. This prediction is consistent with past research that suggests that older adults show exaggerated slowing and more errors in tasks that demand attentional control, such as the color-naming Stroop task (see Spieler, Balota, & Faust, 1996, but see also Verhaeghen, 2011, for an alternative perspective). Applying this to route priming, older adults should show more extreme list context effects, such that they are driven more by list context as opposed to the task set on a given trial. This would manifest as a more robust speedup for target words accessed through the same pathway as the primes (a regular target in a regular block) and a more robust slowdown for target words accessed through the opposite pathways as the primes (an irregular target in a regular block), relative to younger adults who may be better able to modulate between processing pathways for optimal performance.

Second, one might also predict reduced pathway priming in older adults relative to younger adults because of their increased exposure to language. To the extent that older adults are able to mitigate inhibitory deficits in a more practiced domain such as language, one might expect smaller, or equal, effects of route priming overall in older adults relative to younger adults. To adjudicate between these possibilities, independent assessments of vocabulary (Shipley, 1940; Zachary, 1992), and attention control (the Operation Span task: McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010, and the

Stroop task: Stroop, 1935) were included to address the relations among attention, vocabulary, and pathway control in younger and older age groups.

There were several specific predictions involving the measures of vocabulary and attention. First, we expected exaggerated route priming with lower attentional control; so a within- and between-groups negative correlation of attention with magnitude of route priming. Second, the metrics of vocabulary, particularly within the group of older adults, might be negatively correlated with magnitude of route priming. Supporting this prediction is some experimental evidence suggesting that participants with higher lexical integrity show less semantic priming, as well as decreased evidence of lexical and semantic effects on word naming performance (Yap, Balota, Sibley, & Ratcliff, 2011). To draw a distant comparison, the prediction above is again supported: vocabulary may be negatively associated with route priming, since those high in lexical integrity are less susceptible to manipulations of context and support. Because older adults are both higher in vocabulary (predicted to be negatively correlated with magnitude of route priming) and lower in attentional control (predicted to be positively correlated with magnitude of route priming), including these individual difference measures allow fine-grain comparisons where detail might otherwise be lost.

Method

Participants

Younger adult participants (N = 37) were undergraduate students recruited from the Washington University volunteer participant pool. Older adult participants (N = 44) were community-dwelling adults between 47 and 86 years old and were recruited from the Aging and Development participant pool. Younger adults chose between course credit and monetary compensation ($10), and older adults were offered monetary compensation for their time ($10). All participants were native English speakers and did not self-report any significant vision or hearing problems. Mean age for younger adults was 19 years (SD = 1.3), and mean age for older adults was 74 years (SD = 7.2). There was a significant difference in education levels between younger adults ($M = 13$ years, $SD = 1.1$) and older adults ($M = 16$ years, $SD = 2.7$), $t(76) = 5.10$, $p < .001$.

Stimuli

The primes consisted of 93 regular and 93 irregular verbs. Independent-sample *t* tests were performed on the length and HAL frequency (Lund, Burgess, & Atchley, 1995) of the regular versus irregular prime verbs to ascertain that they did not differ on these dimensions, see Table 1 (all *p*s > .05). A different set of 20 regular and 20 irregular verbs were selected as target items. Regular and irregular targets did not differ on length or log frequency (all *p*s > .05), see also 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, on average, five intervening primes. An example of a regular and irregular list is presented in Appendices A and B. Regular and irregular targets appeared equally often in the two blocks but this was counterbalanced across participant so that each target was ultimately seen in both contexts, but no word was seen more than once per participant.

Table 1. *Stimuli Characteristics*

	Primes		Targets	
	Regular	Irregular	Regular	Irregular
Length	5.25	5.00	5.1	4.9
Log HAL Frequency	8.24	8.92	9.63	9.73

Procedure for the Route Priming Task

As seen in Figure 1, each trial consisted of (a) a 500-millisecond (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, and (d) a 500-ms inter-trial interval consisting of a blank screen. Participants were asked to name the past tense of the presented verb aloud, and response times (RTs) were recorded using a voicekey. Participants were encouraged to respond as quickly and as accurately as possible. When a response was detected by the voicekey, the target onscreen was replaced by a blank screen during which the experimenter coded accuracy— both primes and targets were classified as correct, incorrect, microphone error/dysfluency, or regularization error (e.g., "runned" instead of "ran"). Following this coding, the inter-trial interval was initiated.

Participants were presented with a practice block of eight trials, followed by two blocks of the experiment with a rest break in between. The experimental blocks consisted of 113 trials and each of the targets occurred after 3-7 primes. Participants saw two blocks of the experiment, one with regularly-inflected primes and one with irregularly-inflected primes. Prime block order was counterbalanced across participants, so that half received the regular prime block first, and half received the irregular prime block first.

Attention and Vocabulary Measures

Following the past tense route priming task, several additional measures were administered. The mean level of performance in each of these tasks is displayed in Table 2. First, participants completed the operation span task (McCabe et al., 2010), a complex working memory measure in which participants were asked to read aloud and solve math

Table 2. *Descriptives of individual difference measures by age group*

	Younger Adults		Older Adults	
	M	SD	M	SD
Stroop RTs				
Incongruent	753	117	1006	189
Neutral	678	102	858	159
Congruent	633	105	794	160
Stroop Effect	120	61	212	98
Stroop Mean Z-scores				
Incongruent	.42	.23	.61	.23
Neutral	-.07	.19	-.14	.18
Congruent	-.36	.16	-.44	.17
Stroop Effect	.79	.34	1.05	.36
Stroop Mean Errors				
Incongruent	3.69	3.75	4.93	6.04
Neutral	1.19	1.91	2.19	5.28
Congruent	1.07	1.84	1.15	1.26
Stroop Effect	2.62	4.50	3.78	4.83
Span				
Span Length	3.05	1.45	2.45	2.02
Total Correct	8.84	3.92	6.68	5.37
Shipley Vocabulary				
Total Correct	33.43	2.53	36.19	2.48
Vocab Age	18.86	.79	19.68	.77
Time	2.57	1.04	4.24	1.30

problems while remembering the second digit in an equation. For example, they were presented with the equation “4 + 5 = 10,” and they were required to read it aloud, say “incorrect,” then remember the 5. After two to seven of these equations, a screen instructing them to recall all of the presented digits appeared, and they typed the memory items in the order they were originally presented. After a practice round, the task began at a difficulty of one equation per trial but increased by one additional equation after every three trials, provided the participant correctly recalled all of the digits on at least two of the recall trials. Once the participant responded incorrectly on two out of three trials, or reached the ceiling of seven problems, the task terminated. Participants’ performance was measured both in total number of correct recall trials (maximum of three per level) and in span length (e.g., the highest level they reached with 2/3 proportion correct).

Following the operation span task, the Shipley Institute of Living vocabulary subscale (Shipley, 1940, & Zachary, 1992) was administered. This consisted of a series of 40 trials in which participants were asked to match a target item to its synonym from four possible options provided. Performance in this task is measured by number correct, vocabulary age, and time taken to complete the task.

Finally, a Stroop color-naming task (Stroop, 1935) was given to participants. The stimuli in this task were the words green, blue, yellow, red, legal, deep, bad, and poor, and they appeared in the colors green, blue, yellow, or red. Participants were instructed to say aloud the color of the target word onscreen. They saw: (a) a row of plus-sign fixations for 500 ms, (b) a 50-ms blank screen, (c) the color-naming target for 5000 ms or until a verbal response was detected by the voicekey, and (d) a 750-ms blank screen which served as the inter-trial interval. Experimenters coded the responses by pressing a key corresponding to what was said aloud by the participant (“blue”, “yellow”, “red”, “legal”, “deep”, “bad”, or “poor”), or by pressing a key that indicated the voicekey was triggered by a microphone error. Participants received 80 trials: 32 congruent trials (the word “blue” presented in blue ink), 24 incongruent trials (the word “green” presented in blue ink), and 24 neutral trials (the word “deep” presented in blue ink). Performance was assessed using the difference in performance between congruent and incongruent trials in the context of three dependent variables: raw reaction time, z-scored reaction time, and proportion correct.

Results

To ensure that extreme scores did not unduly influence the results, outliers were eliminated in the following manner: First, RTs that were under 200 ms and over 3000 ms were trimmed. Following this, an individually-based trimming procedure was performed in which RTs falling outside of 3 standard deviations from each participant’s mean were trimmed. The overall percentage of outliers identified by following this procedure was 1.5%. Mean RTs and z-scores, excluding any errors, and mean proportion correct, were then computed. Mean proportion of regularization errors was also calculated for the irregular targets.

Analyses were conducted on both the participant-level (F_1) and the item-level means (F_2). For each analysis, we conducted 2 (Context Type: regular or irregular verb) by 2 (Target Type: regular or irregular verb) by 2 (Age: younger or older adults) repeated-measures analysis of variance (ANOVA) on mean RT, z-scored RT, and proportion correct. Z-scores were used in order to compare younger and older adults, because the z-transform puts each subject's trial-level data into standardized space and controls for general slowing effects in RT across age groups (see Faust, Balota, Spieler, Ferraro, 1999). We also conducted a one-way repeated measures ANOVA with two levels (Context Type: regular or irregular verbs) on the regularization errors. Because the critical effects are in the Context Type x Target Type interactions, the within-subjects factors will be reported and discussed before the between-subjects factor of age in the following analyses.

Prime Trials

Although the emphasis will be on the target data, it is also important to consider the prime data. Hence, the mean raw RTs, Z-scores, proportion correct, and regularization errors for the prime trials as a function of prime context condition, target condition, and age are reported in Table 3.

The prime trials were assessed by a 2 (context type: regular or irregular) by 2 (age group: young or old) mixed-factors ANOVA. For raw RTs, there was a main effect of context type, F (1, 78) = 107.73, MSE = 973863, p < .001, a main effect of age, F (1, 78) = 107.73, MSE = 973863, p < .001, and a Context Type x Age interaction, F (1, 78) = 11.87, MSE = 107285, p = .001. This interaction reflects the relatively greater difference between the two context types for older adults (M = 220 ms difference between regular and irregular primes) versus younger adults (M = 101 ms difference between regular and irregular primes). For z-scores, there was a main effect of context type, F (1, 78) = 160.51, MSE = 9.19, p < .001, and a marginal Context Type x Age Group interaction, F (1, 78) = 3.23, MSE = .185, p = .076. There was no main effect of age, F (1, 78) = 2.71, MSE = .02, p = .104. Hence, the reliable Context Type x Age interaction appears

Table 3. *Mean response times (RT), Z-scores (Z), overall proportion correct (ACC), and percentage of regularization errors (RE) for primes*

	Regular Primes			Irregular Primes			
	RT	Z	ACC	RT	Z	ACC	RE
Younger Adults	763	-.26	.96	864	.15	.85	.07
Older Adults	949	-.31	.97	1169	.24	.82	.06
Age Difference	186	.05	.01	305	.09	.03	.01

to be greatly diminished in the z-score analysis and reflects the slightly larger difference between regular and irregular primes for older adults (.55 z-units) relative to younger adults (.41 z-units). For proportion correct, there was a main effect of context type, F (1, 78) = 155.06, MSE = .66, $p < .001$, which was qualified by a marginally reliable Context Type x Age Group interaction, F (1, 78) = 3.97, MSE = .02, $p = .050$. This interaction reflects the relatively greater difference between regular and irregular context types in proportion correct for older adults (15% proportion correct difference) relative to younger adults (11% proportion correct difference).

In sum, regular targets were responded to more quickly and accurately than irregular targets by both younger and older adults, and this difference between context types was larger in magnitude for the older adults relative to the younger adults, which appeared to be mostly due to the influence of general slowing. Having examined the prime data, the target data is now the focus of the analyses in the following section, and is displayed in Table 5 (subject-level) and Table 6 (item-level).

Target Response Latencies

For raw RTs, there was a main effect of target type, F_1 (1,76) = 6.38, MSE = 73309, $p = .014$, which was marginal in the item-level analysis, F_2 (1,76) = 2.62, MSE = 58828, $p = .168$, and a main effect of context type, F_1(1,78) = 125.71, MSE = 2778587, $p < .001$, F_2(1,76) = 158.28, MSE = 1269956, $p < .001$. These main effects were qualified by a Target Type x Context Type interaction, F_1 (1,78) = 77.43, MSE = 822089, $p < .001$,

Table 4. *Mean response times (RT), Z-scores (Z), overall proportion correct (ACC), and percentage of regularization errors (RE) for targets, subject-level*

Younger Adults (N = 37)

	Prime Type							
	Regular Verb				Irregular Verb			
Target	RT	Z	ACC	RE	RT	Z	ACC	RE
Regular	717	-.44	.98		898	.29	.97	
Irregular	794	-.12	.76	.18	847	.10	.86	.08
Regularity Effect	**77**	**.32**	**.22**		**-51**	**-.19**	**.11**	

Older Adults (N=46)

	Prime Type							
	Regular Verb				Irregular Verb			
Target	RT	Z	ACC	RE	RT	Z	ACC	RE
Regular Verb	866	-.57	.98		1262	.43	.92	
Irregular Verb	1054	-.11	.77	.10	1171	.16	.81	.05
Regularity Effect	**188**	**.46**	**.21**		**-91**	**-.27**	**.11**	

Table 5. *Mean response times (RT), Z-scores (Z), overall proportion correct (ACC), and percentage of regularization errors (RE) for targets, item-level*

Younger Adults (N = 37)

	Prime Type							
	Regular Verb				Irregular Verb			
Target	RT	Z	ACC	RE	RT	Z	ACC	RE
Regular Verb	719	-.44	.98		902	.30	.97	
Irregular Verb	805	-.09	.76	.19	856	.13	.86	.08
Regularity Effect	**86**	**.35**	**.22**		**-46**	**-.17**	**.11**	

Older Adults (N=46)

	Prime Type							
	Regular Verb				Irregular Verb			
Target	RT	Z	ACC	RE	RT	Z	ACC	RE
Regular Verb	868	-.55	.98		1245	.42	.93	
Irregular Verb	1066	-.08	.77	.10	1167	.18	.81	.05
Regularity Effect	**198**	**.47**	**.21**		**-78**	**-.24**	**.12**	

F_2 (1,76) = 52.05, *MSE* = 417627, $p < .001$. The interaction reflects the fact that the nature of the difference between regular and irregular target verbs changes depending on the list context. Specifically, the regular targets are faster than the irregular targets when preceded by a series of regular primes, t_1 (36) = 4.08, $p < .001$, t_2 (38) = 3.40, $p = .002$ for younger adults and t_1 (42) = 2.60, $p = .013$, t_2 (38) = 4.70, $p < .001$ for older adults. This pattern is reversed in the irregular context, such that reaction time for irregular targets is faster than reaction time for regular targets, t_1 (36) = 7.67, $p < .001$, t_2 (38) = 1.50, $p = .143$ for younger adults and t_1 (42) = 3.20, $p = .003$, t_2 (38) = 1.40, $p = .169$ for older adults.

There was also a significant age effect, F_1(1,78) = 34.53, *MSE* = 287841841, $p < .001$, F_2(1,76) = 115.47, *MSE* = 2827385, $p < .001$, a Context Type x Age interaction, F_1(1,78) = 17.56, *MSE* = 388096, $p < .001$, F_2(1,76) = 18.50, *MSE* = 148405, $p < .001$, and a Context Type x Target Type x Age interaction, F_1(1,78) = 10.92, *MSE* = 115940, $p = .001$, F_2(1,76) = 6.55, *MSE* = 52515, $p = .013$. This significant three-way interaction is displayed graphically in Figures 2 and 3, and reflects a similar regularity effect across age groups for the irregular context (an average 36-ms difference between age groups in subject and item-level means), but a larger regularity effect for older adults (average 193 ms regularity effect) than for younger adults (81.5 average ms) for the regular context. This was confirmed by independent samples *t* tests between older and younger adults for the regular context, which was significant, t_1 (78) = 3.05, $p = .003$, and irregular verbs, which was not significant, t_1 (78) = 1.27, $p = .21$.

Figure 2. *Subject-Level Raw RTs, Z-scores, Proportion correct, and Regularization Errors by Age Group*

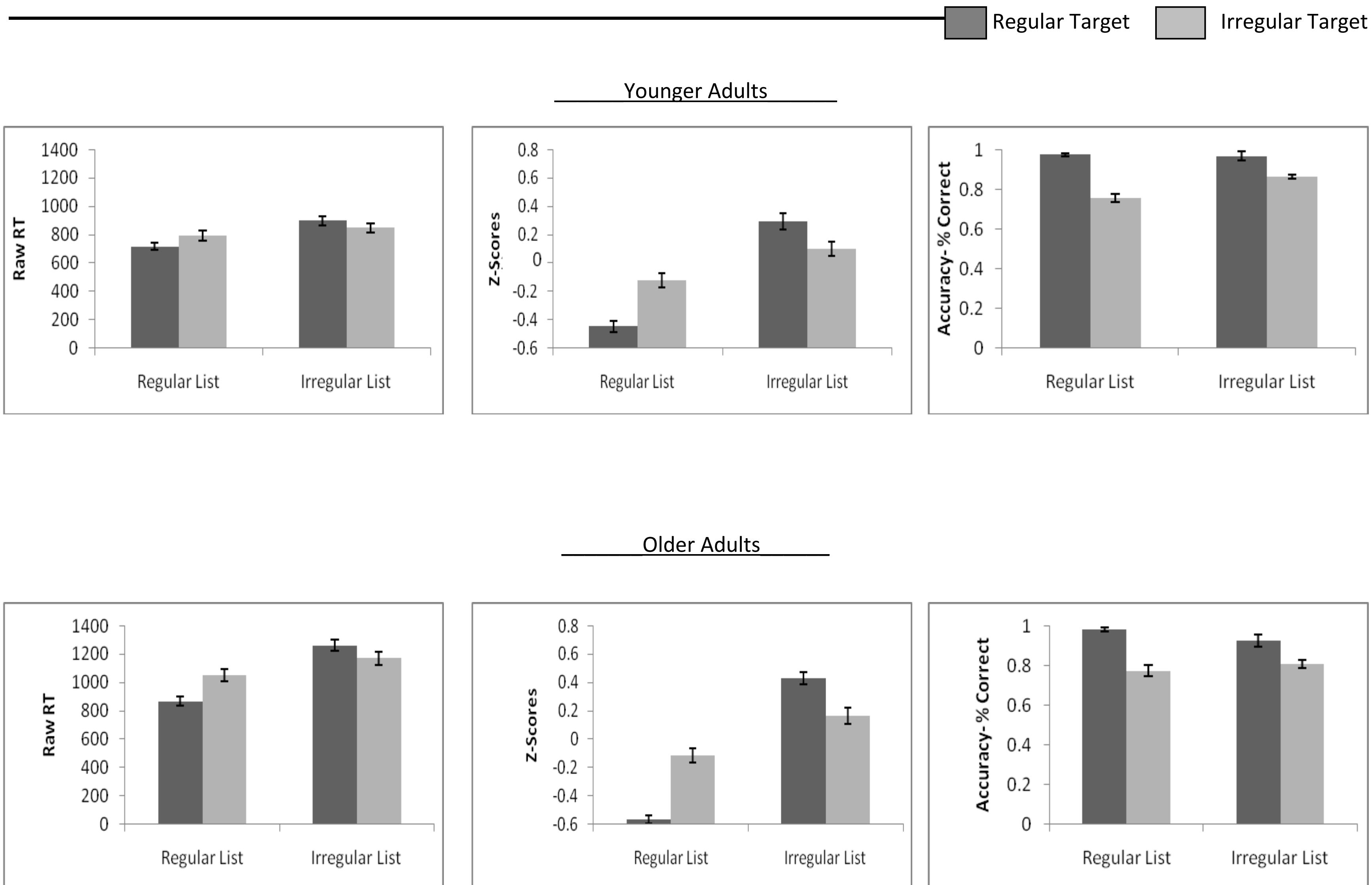
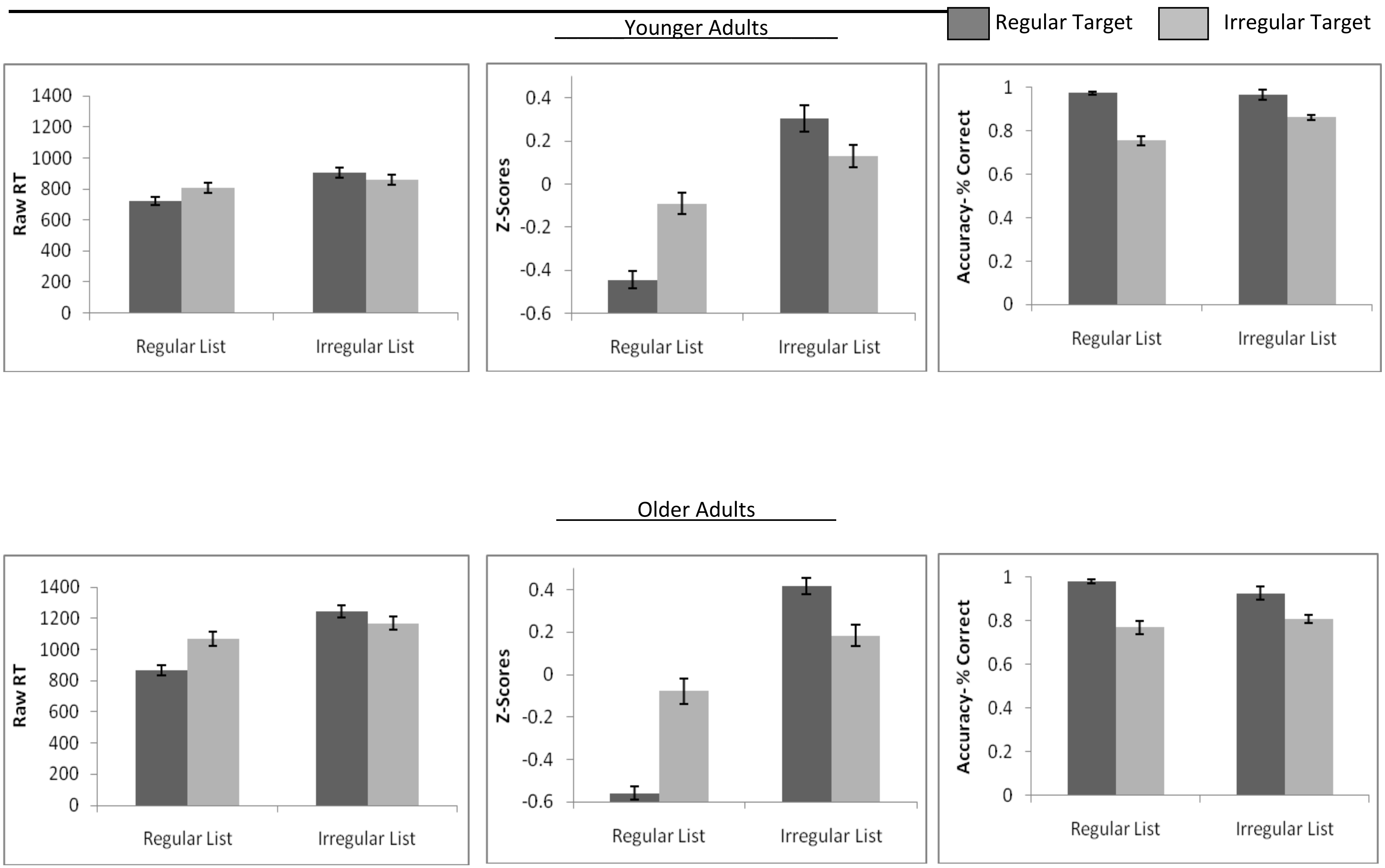


Figure 3. *Item-Level Raw RTs, Z-scores, Proportion correct, and Regularization Errors by Age Group*



Target Z-scores

The results from analyzing the z-scores are similar to raw RTs, with the exception of an elimination of the main effect of age. Of course, this is expected, given that standardizing scores has been shown to account for general slowing observed in older adults relative to young adults (Faust et al, 1999). There was a main effect of target type, $F_1(1,78) = 5.28$, $MSE = .51$, $p = .024$, which was marginal in the item analysis, $F_2(1,76) = 2.39$, $MSE = .450$, $p = .126$, and a main effect of context type, $F_1(1,78) = 153.88$, $MSE = 24.92$, $p < .001$, $F_2(1,76) = 211.89$, $MSE = 12.18$, $p < .001$, but these were qualified by a Context Type x Target Type interaction, $F_1(1,78) = 87.42$, $MSE = 7.57$, $p < .001$, $F_2(1,76) = 67.21$, $MSE = 3.86$, $p < .001$. The interaction reflects opposite influences of target regularity as a function of prime context. Specifically, the regular targets are faster than the irregular targets in the regular context, t_1 (36) = 4.32, $p < .001$, t_2 (38) = 4.10, $p < .001$ for younger adults and t_1 (42) = 9.87, $p < .001$, t_2 (38) = 5.2, $p < .001$ for older adults. This pattern is reversed in the irregular context: irregular targets are faster than regulars, t_1 (36) = 2.70, $p = .01$, t_2 (38) = 1.50, $p = .15$ for younger adults and t_1 (42) = 9.87, $p = .001$, t_2 (38) = 1.70, $p = .098$ for older adults.

Though the overall age effect was not significant, it is noteworthy that the three-way interaction among Target Type x Context Type x Age approached significance, F_1 (1, 78) = 2.35, $MSE = .20$, $p = .129$, F_2 (1,76) = 1.50, $MSE = .086$, $p = .225$, which is the pattern of results found in the raw RTs. Specifically, there is a numerically larger difference between younger and older adults in the regularity effect for the regular list context (a .13 z-unit average age difference) relative to the irregular context (.075 z-unit average age difference). However, again, these data need to be treated with caution because the overall three-way interaction did not reach significance.

Target Accuracy

For proportion correct, there was a main effect of target type, F_1 (1,78) = 152.50, *MSE* = 2.09, $p < .001$, F_2 (1,76) = 44.74, *MSE* = 1.069, $p < .001$, and a Target Type x Context Type interaction, F_1 (1,78) = 21.89, *MSE* = .205, $p < .001$, F_2 (1,76) = 11.39, *MSE* = .109, $p = .001$. This interaction reflects the larger difference between regular and irregular targets in the regular list context, t_1 (36) = 8.70, $p < .001$, t_2 (38) = 4.10, $p < .001$ for younger adults and t_1 (36) = 7.90, $p < .001$, t_2 (38) = 6.40, $p < .001$ for older adults, than in the irregular list context, t_1 (36) = 5.70, $p < .001$, t_2 (38) = 2.60, $p < .015$ for younger adults and t_1 (38) = 4.80, $p < .001$, t_2 (38) = 3.60, $p = .001$ for older adults.

The only significant influence of age in the subject- or item-level analyses with respect to the proportion correct was a marginal Context Type x Age interaction, F_1 (1,78) = 7.33, *MSE* = .072, $p = .008$, F_2 (1,76) = 3.46, *MSE* = .033, $p = .067$. To explore this interaction, post hoc *t* tests were conducted on overall proportion correct by context type, collapsing across target type. These analyses suggested that younger and older adults do not differ on target proportion correct in regular lists, t_1 (78) = .57, $p = .568$, t_2 (78) = .28, $p = .781$, in which older adults are only 0.5% more accurate than younger adults. However, they do differ marginally in proportion correct on targets in irregular lists, t_1 (78) = 1.86, $p = .066$, t_2 (78) = 1.62, $p = .110$, in which younger adults are about 5.0% (subject-level) and 4.5% (item-level) more accurate than older adults.

Regularization Errors

For regularization errors, a 2 (Prime Type) x 2 (Age Group) mixed-factors ANOVA was conducted. There was a main effect of context type, F_1 (1,78) = 25.87, *MSE* = .246, $p < .001$, F_2 (1,38) = 13.60, *MSE* = .130, $p = .001$, indicating that there were more regularization errors in the regular context than the irregular context. There was a main effect of age in the subject-level analyses, F_1 (1,78) = 8.64, *MSE* = .107, $p = .004$, that did not reach significance in the item level analysis, F_2 (1,19) = 1.60, *MSE* = .054, $p = .214$, but reflects relatively higher regularization error rates for the younger adults than the older adults (see Figure 4).[1]

In sum, the target data displayed evidence that participants were attentionally selecting a processing pathway most efficient for the list context. In the regular context, regular verbs were processed more quickly than irregular verbs, whereas irregular verbs were processed quicker than regular verbs in the irregular context. Despite this pattern of

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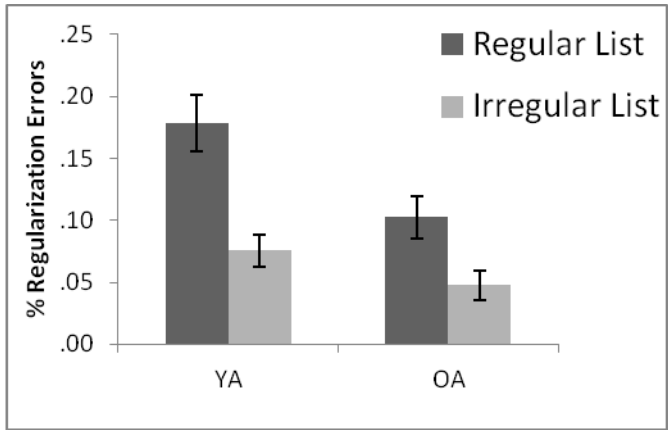
[1] Because participants saw both blocks, we assessed the effect of order on performance. For raw RT, there was no significant effect of order, F_1(1,76) = .004, *MSE* = 658, $p = .949$, F_2(1,152) = .79, *MSE* = 24348, $p = .375$, but the Age x Order interaction was significant, F_1(1,76) = 9.25, *MSE* = 1463855, $p = .003$, F_1(1,152) = 36.86, *MSE* = 1134921, $p < .001$. This interaction reflects the fact that in overall RTs collapsing across context and target type, younger adults were 130 ms faster when they received the irregular block first, and older adults were 121 ms faster when they received the regular block first. For z-scores, there was a marginal main effect of counterbalancing order in the subject-level analyses, F_1(1,76) = 3.74, *MSE* = .145, $p = .057$, F_2(1,152) = .24, *MSE* = .05, $p = .629$, as well as a Context Type x Order interaction, F_1(1,78) = 6.82, *MSE* = 1.038 $p = .011$, which approached significance in the item-level analyses, F_2(1,152) = 2.62, *MSE* = .34, $p = .108$. This interaction, though only significant in the subject-level analyses, reflects the fact that targets embedded in the regular list were not affected by order, t (78) = 1.60, $p = .112$, but targets embedded in the irregular list were, t (78) = 2.83, $p = .006$. There was no effect of order on proportion correct, F_1(1,76) = .008, *MSE* = .000, $p = .931$, F_2(1,152) = .005, *MSE* = .000, $p = .941$.

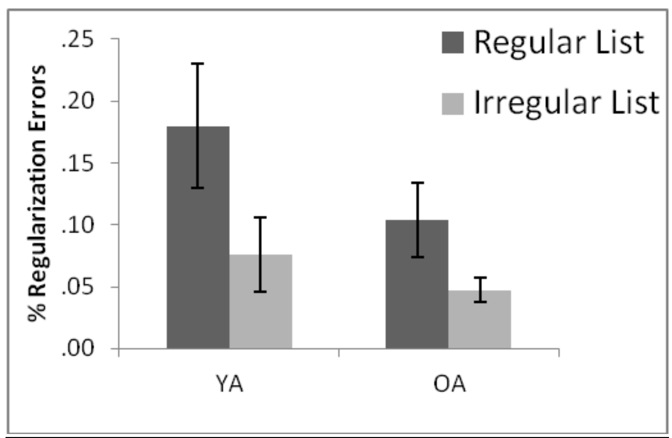
The existence of order effects indicated that a set of analyses on only the first block of data would be useful. These results of these analyses were very similar to those using the full dataset with two exceptions: for younger adults, there was no effect of prime type for either target type in the subject-level raw RTs, ps > .05 (but this is not entirely surprising, since the effect in raw RTs is also absent in the item-level analyses, even with the full dataset), and in the analysis of older adults' item-level raw RTs, there was only a marginal effect of prime list type on the irregular targets, $t(19) = 1.67$, $p = .112$.

Figure 4. *Subject- and Item-Level Regularization Errors by Age Group*

Subject-Level



Item-Level



route priming in raw and z-scored reaction time, the accuracy data show overall greater proportion correct for regular targets than irregular targets. This regularity difference, however, is smaller in the irregular context, in which accuracy for the irregular verbs approaches that for the regular verbs. Finally, younger and older adults seem to be showing only a slightly different pattern of results to target verbs; there are overall age differences in raw RT, but these are non-significant once the more appropriate z-score comparison is conducted. On a more detailed level, older adults show a larger route priming effect in raw RTs to regular verbs than younger adults do, but both age groups show similar magnitudes of route priming to irregular verbs.

Attention and Vocabulary Measures

The Stroop, span, and vocabulary results are displayed in Table 2. First, the raw RT, z-score and proportion correct data from the Stroop task were subjected to a 3 (Condition: congruent, incongruent, neutral) x 2 (Age: young, old) mixed-factors ANOVA. For raw RT, there was a main effect of condition, F (2,140) = 224.98, MSE = 523641, $p < .001$. Responses were fastest in the congruent condition, followed by the neutral condition, and finally were slowest in the incongruent condition; post hoc t tests using the Bonferroni correction for multiple comparisons revealed that all three conditions differed from one another, ps < .001. There was also a main effect of age, F (2,140) = 39.27, MSE = 2219284, $p < .001$, such that younger adults were faster than older adults, as well as a Condition x Age Group interaction, F (2,140) = 19.45, MSE = 45276, $p < .001$, which reflects a relatively greater Stroop effect (212ms) for older adults than younger adults (119ms). For z-scores, there was a main effect of condition, F (2,142) = 302.07, MSE = 15.95, $p < .001$, and a Condition x Age Group interaction, F (2,142) = 7.63, MSE = .403, $p = .001$, which reflects a relatively greater Stroop effect (1.05 z-units) for older adults than younger adults (.79 z-units). For the proportion correct data, there was again a main effect of condition, *F* (2,142) = 22.07, MSE = .024, $p < .001$, and no main effect of age, *F* (1,71) = .19, MSE = .001, $p = .661$, or Condition x Age interaction, *F* (1,71) = .93, MSE = .001, $p = .398$. Post hoc tests revealed that proportion correct in the incongruent condition was significantly lower than in the congruent and neutral conditions, *p*s < .001, which did not differ in overall proportion correct, $p = .390$.

In addition to the Stroop task, the operation span task was administered as another measure of attentional control. The dependent variables discussed are span length (i.e., how many items can be stored in memory while performing the concurrent task) and span total (i.e., the total number of memory targets recalled across all trials in the span task). There were age differences in performance on the span task, though only in total span items recalled, *t* (71) = 2.00, $p = .049$, and not in span length, *t* (71) = 1.49, $p = .139$.

Turning now to performance on the vocabulary task, the Shipley Institute of Living Vocabulary subscale (Shipley, 1940, & Zachary, 1992) yields several different measures of performance. Total number correct, raw score, vocabulary age, and time taken were the output measures given by this task. An individual samples *t* test revealed a significant effect of age in both measures. Older adults showed better performance on the vocabulary age measure, *t* (72) = 4.53, $p < .01$, and were also slower to complete the task, *t* (72) = 6.12, $p < .01$, than younger adults.

To assess the individual difference measures' relations to performance on the past tense route priming task, correlational analyses were conducted on measures of attention, vocabulary, and the regularity effect in regular and irregular lists. First, Stroop effects in speed or accuracy were not correlated with span length or span total. This is in contrast to Hutchison (2007), where span length and Stroop effect were correlated, $r = .25$, $p < .01$, and enabled the creation of a (more reliable) composite measure. Because this was not possible in the current study, Stroop and span results are analyzed separately.

First, the only correlation between the attentional tasks and the regularity effect in route priming was for younger adults, the Stroop effect in RTs was positively associated with the regularity effect in accuracy in the irregular list, $r = .40$, $p = .017$. The vocabulary measures were positively correlated with the magnitude of the regularity effect for younger adults; for number correct on the vocabulary task and the regularity effect for the regular context in raw RTs, $r = .51$, $p = .001$, and in z-scores, $r = .33$, $p = .047$. The younger adults' regularity effect in accuracy in the irregular context was also correlated with number correct on the vocabulary task, $r = .36$, $p = .030$.

Discussion

The results of the current study provide support for both the processing pathway approach and the attentional control hypothesis in the domain of past tense inflection. Specifically, regular verbs were processed more quickly than irregular verbs in a rule-pathway biasing context, whereas irregular verbs were processed more quickly than regular verbs in a word-pathway biasing context. The ability of a contextual manipulation to have an impact upon performance demonstrates strategic adjustment of attention to past tense processing pathways based upon the task demands created by the list context. It is noteworthy that the full crossover was not found in the accuracy data; rather, regular items are overall more accurately conjugated than irregular items. This effect, however, was in the predicted direction; that is, the greater accuracy of regular targets over irregular targets was diminished in the irregular list. Additionally, the percentage of regularization errors (e.g., RUNNED) was 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.

Alternative Hypothesis—Time Criterion

An important consideration in route priming research, which also has general implications for many reaction time studies, is the difference in overall response latencies between the regular and irregular prime blocks, and whether this might explain some of the differences in target performance attributable to route priming. In the current study, the overall speed disparity between the two blocks is approximately 100 ms for younger adults and 200 ms for older adults. In fact, Lupker and colleagues (1997) used the time criterion hypothesis as an alternative explanation of results that seem to be supportive of the attentional control hypothesis. For example, they reframed the Monsell et al (1992) finding, discussed in the Introduction, of a benefit for target items in a pure-block condition relative to a mixed-block condition as an effect of overall response latencies across items in the different blocks. Specifically, blocks in which all primes are fast (pure-block) encourage a fast response articulation deadline on target trials, whereas blocks in which all primes are slow (mixed-block), encourage a slower response articulation deadline on target trials. This hypothesis was further supported by experiments by Taylor and Lupker (2001) in which they found that any targets following fast primes are pronounced faster than the same targets following slow primes.

With the manipulations of list context in route priming experiments, where the distinction is not pure versus mixed blocks but some effect examined in two different contexts, one way to assess the time criterion account is to consider the effect of interest (the regularity effect, in the current study) at the two prime blocks' average latency. In the current study, the operation of a time deadline would predict a change in the regularity effect depending on whether the targets were embedded in a (fast) regular or (slow) irregular context. Specifically, one might predict a smaller regularity effect in the slower condition because the regular verbs have so much further to slow down than the irregulars, thus pulling their response latencies closer together, or homogenizing them. Indeed, a homogenization of response latencies to fast and slow targets in a slow prime list is exactly what Taylor and Lupker (2001) found when they manipulated list context in a similar fashion to route priming experiments such as in the current study and measured word naming. Importantly, the present results cannot be accommodated in this manner, because there was not simply a decrease in the size of the regularity effect in the slow block, but rather a complete crossover in the regularity effect across the fast and slow list context conditions. This crossover is at odds with any prediction of the time criterion account.

Another way to examine the results for the operation of a time criterion is to partial out overall prime speed and run the same analyses on the data. This is a statistical attempt to equate latencies in the two prime blocks, and was done on all participants' first-block data, with overall prime speed on that block as a covariate. When this was done for raw RTs, the main effect of target is now marginal (but still in the same direction), F (1, 75) = 3.22, MSE = 43624, p = .077, and there is still a main effect of list context, F (1, 75) = 6.03, MSE = 139855, p = .016. The critical Target Type x Context Type interaction, F (1, 75) = 30.64, MSE = 415552, p < .001, as well as the three-way Target Type x Context Type x Age interaction, F (1, 75) = 8.36, MSE = 113342, p = .005, are both still significant. The nature of this interaction changes slightly, in that the older adults are still exhibiting the crossover interaction where regular verbs are faster than irregulars in the regular context and vice versa for the irregular context, but for younger adults, the regular targets are faster than irregular targets in the regular condition, and there is an elimination (rather than reversal) of this effect in the irregular context.

The z-score analyses further suggest that a time criterion hypothesis cannot account for the current results, since the critical effects remained the same in the z-score analyses after partialling out overall prime speed: there was a marginal main effect of target type, F (1, 75) = 3.49, MSE = .399, p = .066, and a main effect of context type, F (1, 75) = 5.16, MSE = .371, p = .026, qualified by a Target Type x Context Type interaction, F (1, 75) = 6.43, MSE = .737, p = .013. This interaction still reflected a crossover effect in the regularity effect depending on list context, such that regular verbs were pronounced faster than irregular verbs in the regular context, but the reverse was true for the irregular context. The between-subjects variable of overall prime speed was significant in the z-scores, F (1, 75) = 7.47, MSE = .731, p = .008, despite all effects remaining the same when it was included in the analyses. It is important to note that this is not the case because of any redundancy in statistical analysis: the construction of the original z-scores upon which this analysis was conducted took into account overall response latency to the *target* items, whereas z-scored overall *prime* speed is what was covaried out in these analyses.

Taken together, both the crossover regularity effect in both raw and z-scored response latencies, and the fact that the critical route priming findings remained the same when overall prime speed was partialled out, rule out the explanation of the present results as an adoption of different response deadlines in the regular and irregular verb list contexts.

Aging and Route Priming

An important additional feature of the present study is the inclusion of a comparison of younger and older adult participants, but the results on this dimension are not entirely clear. As discussed in the Introduction, there are a number of intriguing predictions regarding possible age differences in route priming. A typical route priming task involves components that are thought to change with age: suppression of a biased, or prepotent, response for incongruent targets (which is thought to decline with age), as well as language usage (which is thought to improve with age). The predictions laid out in the Introduction are derived from these components; the first prediction was that older adults would have more difficulty controlled the biased pathway. This was only supported in the raw RTs, and marginally in the proportion correct data. In fact, older adults exhibited fewer regularization errors than younger adults. However, there is a marginal context by target by age interaction in the z-scores. Thus, the nature of this interaction is crucial to the interpretation of the results in terms of aging. It may be the case that there really is a three-way interaction, and the experiment failed to detect it. Power is notoriously low for interactions, particularly those of higher order such as the 3-way interaction in the current study (Cohen, 1992). Additionally, there are issues inherent in examining age in such extreme groups.

The second prediction laid out in the Introduction is that older adults' increased exposure to language may mitigate their inhibitory deficits and they might show the same, or even less, route priming than younger adults. Given the marginal three-way interaction in z-scores, and the underwhelming age differences in accuracy measures, the data seem to indicate that younger and older adults are showing similar past tense route priming performance. However, the hypothesized cause of this similarity was not borne out in the attention and vocabulary individual difference measures. First, the attentional measures were not correlated with measures of the regularity effect. This may be a limitation caused by unreliable measures; the typical test-retest reliability of a computerized Stroop task, for example, is .35 (D. Balota, personal communication).

The vocabulary measures, on the other hand, were positively correlated with the magnitude of the regularity effect for younger adults. This finding of larger regularity effects with higher vocabulary parallels the three-way interaction in RTs, where older adults (a group with higher overall vocabulary) show larger regularity effects than younger adults (lower overall vocabulary). These associations between vocabulary and the magnitude of route priming do not provide any elucidation of older adults' relatively intact performance on the route priming task; in fact, they seem to suggest that both older adults as a group and younger adults with high vocabulary are more strongly biased by the local list context.

General Conclusions

The current study examined pathway control in past tense route priming, and challenged current models of past tense inflection. The cross-over interaction for the regular and irregular target words as a function of list context would at first glance appear to be problematic for an unembellished single-route model of past tense inflection. However, a similar issue has arisen with the route priming studies in naming, and it was addressed by invoking a triangle-type architecture (hypothesized in Seidenberg & McClelland, 1989, and implemented in Plaut, McClelland, Seidenberg, and Patterson, 1996), in which a set of semantic units was added to the existing phonological and orthographic units. This allows information to travel from the orthography straight to phonology, as well as through semantics to phonology. If the relative contributions of the different word mappings (direct from orthographic to phonological vs. semantically mediated) were influenced by the list context, single-route connectionist models might account for route priming results in word naming. Theoretically, a similar implementation of additional sources of information might work for past tense models as well.

The difference in target performance observed with changes in list context appears more consistent with a dual-route framework. One could imagine the dual-route perspective predicting a diminished, or nonexistent, regularity effect when the "word" pathway is biased (as when the list context is made up of irregular verbs). The present crossover interaction suggests complete 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 this point it is interesting to note that the route priming results in word naming do not show a complete cross-over, but rather a diminished effect of the targeted variable across blocks. Specifically, Zevin and Balota (2000) found that exception words produced worse performance than regular verbs across nonword and exception word context blocks, but the effect was much larger in the nonword context block. Hence, there was not a complete reversal of the word frequency effect in the block thought to de-emphasize the role of regularity. Presumably there is something particular to past tense conjugation that leads to complete removal of competition for the irregular items. One possibility is that a route biasing manipulation is more direct in past tense inflection than in word naming. In this situation, converting present tense verbs into the past tense affords more direct access to the inflection process, whereas, word naming provides relatively less direct access to the process of converting graphemes to phonemes due to the ease and frequency of reading words aloud.

In summary, the current study provides the first evidence for route priming in a domain other than word naming. The results indicate that the route priming demonstrated in studies of word naming was also, to a large extent, borne out in the domain of past tense inflection. Ultimately, the results from this study support the notion of a flexible lexical processor because it highlights that a relatively simple manipulation can modulate the extent to which individuals rely on processes tied to the past tense formation of regular and irregular words. The traditional static linguistic processing models appear to be influenced relatively easily by local biasing context.

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Appendix A. *Prime Stimuli*

Regular Primes

ail	electrocute	open	route
amass	endure	own	seat
back	enervate	partition	sensitize
blight	file	pelt	service
buffet	filter	pick	shovel
capture	flunk	place	skim
change	glint	play	slave
clot	gorge	please	sponge
clump	help	point	spout
coerce	hitch	polish	start
combine	impart	post	steer
coo	inoculate	pour	subsist
corner	invest	protest	taste
deign	jab	puke	terrify
deplore	laud	purport	test
devise	leaf	quiet	toil
dimple	list	reap	unleash
dip	loot	recant	use
dissect	mail	reduce	wag
dissipate	mesh	repeat	work
drill	moor	resonate	yellow
droop	nab	retreat	
duck	need	rip	
dupe	occur	rouse	

Irregular Primes

backslide
bear
beget
behold
beset
bite
bleed
blow
breed
build
buy
catch
choose
come
cut
dig
drive
eat
feed
feel
fight
find
flee
fly
foretell
forget
forgo
forsake
freeze
get
go
hide
hit
hold
know
lead
leave
lend
lose
meet
mislead
mistake
outrun
outsell
outshine
overcome
overhang
overhear
override
overrun
oversee
overshoot
overtake
partake
put
read
reset
retell
rewrite
ride
run
say
see
sell
set
shake
shed
shoot
shut
sit
slay
slink
slit
smite
spin
swear
swing
take
teach
tell
tread
unbind
undercut
undergo
underwrite
undo
unwind
uphold
upset
weep
win
wind
withhold

Appendix B. *Target Stimuli*

Regular Targets	**Irregular Targets**
Jump	Awake
Lack	Fling
Check	Sweep
Track	Speak
Thrill	Spend
Cube	Fall
Print	Strike
Stub	Thrust
Stitch	Shrink
Quote	Hurt
Force	Deal
Gain	Give
Scroll	Stand
Approve	Split
Assert	Draw
Charge	Grow
Solve	Bring
Crease	Begin
Stay	Creep
Guide	Arise