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Consistency and regularity in past-tense verb generation in healthy ageing, Alzheimer's disease, and semantic dementia

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Older adults, individuals with dementia of the Alzheimer's type (DAT), and individuals with semantic dementia (SD) produced the past tense of verbs based on present-tense carrier sentences (e.g., Everyday I ding the bell. Yesterday I______the bell). Both regularity (i.e., whether or not -ed is used for the past tense) and consistency (i.e., the degree to which verbs of similar orthography and phonology in the present tense have similar past tenses to the target) were manipulated. Participants received regular consistent (e.g., land–landed), regular inconsistent (e.g., weed–weeded), irregular consistent (e.g., sting–stung), and irregular inconsistent (e.g., light–lit) verbs. The dependent measures were overall accuracy rates and error rate types (e.g., regularizations, analogies, and other errors). Both consistency and regularity influenced performance. In addition, individuals with DAT showed a disproportionate deficit for inconsistent verbs associated with a high summed frequency of enemies, whereas SD individuals produced disproportionate breakdowns in performance on regular inconsistent, irregular consistent, and irregular inconsistent verbs. These results are consistent with the perspective that semantic/lexical processes are involved in processing the past tense of both irregular verbs and regular inconsistent verbs, and that attention is used to select appropriate responses and control inappropriate responses.

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The manner in which people process words varying in the linguistic "rules" of a language has greatly influenced word-processing theories (e.g., Baron & Strawson, 1976; Cortese & Simpson, 2000; Patterson, Lambon Ralph, Hodges, & McClelland, 2001; Tyler et al., 2002; Ullman et al., 1997). Consider the process of past-tense verb generation. A verb is regular if it follows the add -ed rule (e.g., *matched*) or irregular if it does not follow the add -ed rule (e.g., *slew*). Typically, performance is better for regular verbs than for irregular verbs (i.e., the regularity effect), but the outcome depends on the specific population tested. Of particular interest for the present study is the finding that, compared to healthy older adults, individuals with dementia of the Alzheimer's type (DAT) and individuals with semantic dementia (SD, the temporal lobe variant of frontotemporal dementia) are much less accurate generating the past tense for irregular verbs than that for regular verbs (for the DAT comparison, see Ullman et al., 1997, and for the SD comparison, see Patterson et al., 2001).[1] Explaining this outcome is central to current theories of past-tense verb generation. Also, the issues that are central to the past-tense verb debate are part of a broader debate on the very nature of language processing itself (e.g., Pinker, 1994; Seidenberg, MacDonald, & Saffran, 2002). Gaining a deeper understanding of the processes involved in past-tense verb processing will likely place fundamental constraints on more general theories of language and cognition.

In addition to regularity, verbs can be defined in terms of their neighbourhood consistency. In general, neighbourhood consistency refers to the degree to which a verb shares both the present- and past-tense phonologies with other verbs. A verb is consistent if other verbs sharing a similar phonology in the present tense also share a similar phonology in the past tense (cf. McClelland & Patterson, 2002). For example, the regular verb *matched*[2] is relatively consistent because most of its neighbours *hatch, latch, patch, scratch*, and *snatch* are "friends" (i.e., they all share similar present and past tenses). *Match* has one "enemy" (*catch*) (i.e., a neighbour that has a similar present-tense phonology and a different past-tense phonology). In contrast, the regular verb *ding*, is relatively inconsistent because most of its neighbours are enemies (e.g., consider the past-tense forms of *sing, ring, sting*, etc.). To illustrate how irregular verbs can vary in terms of degree of consistency, consider the verbs *creep* and *spit*. *Creep* is more consistent than *spit* because it has mostly friends (e.g., consider the past-tense forms of *sleep, keep*, and *weep*) whereas most of *spit*'s neighbours are enemies (e.g., consider the past-tense forms of *fit, knit*, and *hit*).

Interestingly, not many studies have examined consistency effects in verb processing, and no single study to our knowledge has examined regularity and consistency simultaneously. We are aware of only two studies that have addressed this issue. First, in an experiment by Seidenberg and Bruck (1990; subsequently discussed in Seidenberg, 1992) participants were presented visually with the present tense of the verb (e.g., *bake*), and they produced the past tense (e.g., "baked") as quickly and accurately as possible. They found that response latencies were slower to regular inconsistent verbs than to regular consistent verbs. Also, a study conducted by Ullman (1999) demonstrated that the consistency of irregular forms influences naturalness ratings. Specifically, participants provided ratings for how natural a verb appeared to be. For irregular verbs, the more consistent the verb, the more natural it

[1] In contrast, individuals with nonfluent aphasia (NA, e.g., Ullman et al., 1997) have displayed the opposite pattern. However, a recent study by Bird et al. (Bird, Lambon Ralph, McClelland, Seidenberg, & Patterson, 2003) demonstrated that when the phonological complexity of regular and irregular verbs is controlled, there is no difference in the accuracy rates for irregular verbs and regular verbs in NA.

[2] Matched is defined as regular because according to the lexicon and rules (L&R) model (Pinker, 1999), phonological rules are applied after affixation. Specifically, the affix -ed is added to the verb stem, and the pronunciation of that affix is then determined according to the final phoneme of the stem. For stems ending in /ʧ/, the pronunciation of the affix is /t/ (Pinker, 1999).

was rated. Of course, it is unclear what sorts of information participants rely on when making naturalness ratings. In any case, it is clear that there is relatively little empirical evidence that people are sensitive to verb consistency. Moreover, it is important to note here that previous studies have typically confounded regularity and consistency such that regular verbs have also been consistent whereas irregular verbs have also been inconsistent (e.g., Ullman et al., 1997). The importance of decoupling regularity and consistency is exemplified well in the single-word-naming literature (cf. Cortese & Simpson, 2000; Jared, 1997, 2002). In this literature, regularity refers to whether or not a word follows grapheme-to-phoneme correspondence (GPC) rules, and consistency refers to the degree to which words containing similar spellings also contain similar pronunciations. These studies have demonstrated that consistency effects are large, and regularity effects are much smaller. Interestingly, the parallel-distributed-processing (PDP) model of word recognition (Plaut, McClelland, Seidenberg, & Patterson, 1996) accounts for these data quite well whereas the dual-route cascaded (DRC) model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) has difficulty accommodating the results. Therefore, examining both regularity and consistency effects in past-tense verb generation may also constrain the development of analogous theories of verb processing. Furthermore, issues related to regularity and consistency also have implications for other grammatical classes (e.g., nouns) and other language processes (e.g., spelling).

Past-tense verb generation has been interpreted in terms of two distinct theoretical approaches: the lexicon and rules (hereafter L&R) model (Pinker, 1999; Ullman et al., 1997) and the PDP model (e.g., Joanisse & Seidenberg, 1999; Rumelhart & McClelland, 1986). First consider the L&R model of past-tense verb processing. This model includes a mental dictionary (i.e., the lexicon) and a set of morphological rules. To generate the past tenses of verbs, the rule system is utilized for regular verbs (e.g., *matched*), and the lexicon is accessed for irregular verbs (e.g., *slew*). In the L&R model, words and rules are thought to be accessed in parallel (Pinker, 1999). As evidence accumulates for a word in the lexicon, the rule system is inhibited. In general, irregular verbs will be processed more slowly than regular verbs because there is conflict between the two systems, and hence it will take time to suppress the rule system once it has been accessed. Furthermore, the difference in reaction time between regular and irregular verbs should be more apparent for low-frequency verbs than for high-frequency verbs because it will take longer to access a low-frequency irregular verb from the lexicon than a high-frequency irregular verb, and thus the rule system should be more difficult to suppress with time. Ultimately, the rule may be misapplied for an irregular verb either when there is a failure to directly access the past-tense form from the lexicon or if access is very slow. Consistency effects in this model are the result of a verb's neighbours being accessed from the lexicon (Pinker, 1999). In the case of a consistent verb, neighbours facilitate the correct response whereas neighbours of an inconsistent verb interfere with the correct response. A semantic deficit (as in SD) would surface in this model as a lexical processing deficit because semantics is part of the lexicon. Thus, one might expect that a deficit in lexical processing would result in decreased accuracy for irregular verbs. Furthermore, one might expect that representations for low-frequency verbs also would be degraded and might be more greatly affected by neighbourhood consistency. However, because semantics and lexical forms are relatively independent in the model, a deficit to semantics will not always result in damage to lexical forms (see Miozzo, 2003). Therefore, it is possible that there may be increased variability in individuals with SD, with some (i.e., those without a lexical deficit) exhibiting a relatively normal pattern of past-tense verb processing.

The PDP model consists of an interconnected network of simple processing units that learns associations between inputs and outputs. As different versions of the PDP model have been proposed (e.g., Joanisse & Seidenberg, 1999; Rumelhart &

McClelland, 1986), we focus on the more recent model proposed by Joanisse and Seidenberg (1999). The model represents verbs in terms of input phonology, input semantics, and output phonology (Joanisse & Seidenberg, 1999). Knowledge of the relationship between present tense and past tense is coded in the values of weighted connections linking units in a network. According to the PDP view, consistencies at various levels exist in the environment, and people are sensitive to these consistencies. In English, the associations between present-tense forms and past-tense forms are quite systematic, and this consistency gives the illusion of (categorical) rule-governed behaviour. In the model, regularity effects and consistency effects share a common basis. Consistent verbs share stronger connections between input and output phonology, and inconsistent verbs share weaker connections between input and output phonology. For this reason, the semantic system compensates for the weak connections associated with inconsistent verbs. The model posits that regularity and/or consistency effects are the result of weaker input–output connections. Furthermore, the model predicts that damage to the semantic system (as in SD) will affect the processing of inconsistent and irregular verbs more than that of consistent and regular verbs. Interestingly, similar processes are thought to operate for reading aloud (e.g., Plaut et al., 1996), spelling (e.g., Cortese, Balota, Sergent-Marshall, & Buckner, 2003), and noun pluralizing (Haskell, MacDonald, & Seidenberg, 2003).

In addition to the representational characteristics of verb processing that have been detailed in the L&R and the PDP perspectives, one might also consider the importance of attention control systems (cf. Balota, Paul, & Spieler, 1999). For example, processing the past tense of a verb (e.g., *spit*) may result in more than one available form (e.g., *spit, spat, spitted*). Multiple forms could be activated via the lexicon/semantics (e.g., *spat*), the rule system/phonology (e.g., *spitted*), or a combination of systems (e.g., *spatted*). In this scenario, attention may be used to select the appropriate past tense and select against (or inhibit) the inappropriate past tense. Similarly, multiple lexical forms may be activated when reading words (cf. Balota & Ferarro, 1993), repeating words (cf. Gold & Kertesz, 2001), spelling words (cf. Cortese et al., 2003), and accessing the appropriate meaning of an ambiguous word in context (cf. Balota & Duchek, 1991). In all of these domains, one must be able to distinguish between appropriate and inappropriate information. This is particularly relevant to the present study, because there appears to be evidence that individuals with DAT have a breakdown in attentional control systems (see Balota & Faust, 2001; Perry & Hodges, 2000) and so could produce a breakdown in performance, not due to representational changes (as in SD individuals), but possibly due to attentional problems.

In the present study, we examine past-tense verb processing in healthy older adults, individuals with DAT, and individuals with SD. In addition, we also examine regular and irregular verbs that vary in terms of their consistency. Consistent verbs are those that have more friends than enemies, and inconsistent verbs have more enemies than friends. Thus, participants were tested on four types of verb:

1. Regular consistent—*match*
2. Regular inconsistent—*ding*
3. Irregular consistent—*creep*
4. Irregular inconsistent—*spit*

It is important to note that these verb categories were based on the number of neighbours, irrespective of the frequencies of these neighbours. The frequency of friends and the frequency of enemies were assessed via analysis of covariance.

On each trial, individuals read two sentences. The first sentence contained the present tense of the verb (e.g., *Everyday I ding the bell*), and the second sentence contained a blank line where the verb was to be converted into the past tense (e.g., *Yesterday I______the bell*). People read these sentences as quickly and accurately as possible. The main dependent variable was the proportion of correct responses. We also measured regularization errors (e.g., *spitted* for *spat*), analogy errors (*dang* for *dinged*), and other errors (i.e., errors not classified as either regularizations or analogies, e.g., *donged* for *dinged*).

The main questions addressed in this study were: (a) how sensitive are people to the regularity and consistency of past-tense verb forms, (b) how do DAT and SD affect the processing of verbs in the past tense, and (c) how do the theoretical perspective(s) explain the patterns of performance observed in these distinct populations?

Due to the prevalence of the add -ed form in English, we predict robust regularity effects. According to Pinker (1999), there are approximately 10,000 regular verbs and only about 180 irregular verbs in English. We also expect that participants will be less accurate for inconsistent verbs than for consistent verbs. This outcome would be similar to research on consistency effects in reading aloud (e.g., Cortese & Simpson, 2000). In addition, we might expect the consistency effect to be realized in terms of the relative summed frequency of friends and enemies—that is, those past-tense forms with a relatively high frequency of enemies, compared to friends, should show the largest interference effects.

As previously stated, both the L&R model and the PDP model can accommodate regularity and consistency effects. Furthermore, for both models, a breakdown in semantic memory in the individuals with semantic dementia should produce greater disruption for irregular and inconsistent verbs. In the L&R model, this will occur due to the relative locations of lexical/semantic forms in the brain (e.g., Ullman, 2004). In the PDP model, this outcome will occur because the connections between semantic and phonological outputs are richer for irregular and inconsistent verbs. Note, however, that if lexical forms and semantics are represented separately in the L&R model (e.g., Miozzo, 2003), the model can accommodate individuals with selective deficits to semantic memory without an accompanying deficit for irregular verbs, and vice versa.

We might expect qualitatively different patterns to emerge between SD and DAT. In SD deterioration of semantic networks will disrupt connections between semantic/lexical memory and output phonology for irregular and inconsistent verbs while regular and consistent forms will remain more intact. In DAT, if semantic networks are left intact, but attentional control is disrupted, both correct and incorrect forms may be available, but the individual will have difficulty selecting the appropriate form. Moreover, higher frequency competing forms should be more difficult to suppress than low-frequency competing forms. Therefore, we expect competing responses to intrude more often when they are more frequent forms, particularly in DAT.

We propose that multiple forms become activated when processing irregular and/or inconsistent verbs, and individuals with DAT may have difficulty selecting the appropriate response and selecting against (or inhibiting) the inappropriate response. For example, when generating the past tense for *slay* (i.e., *slew*), the regularized form *slayed* may also become activated via the phonological/rule system, and individuals with DAT may have difficulty selecting the correct response. This view is consistent with a body of literature (for a review, see Balota & Faust, 2001; Perry & Hodges, 2000) that has demonstrated inhibition difficulties in individuals with DAT, whereas semantic memory representations in DAT seem to be largely intact when one strips away the attentional control properties of a task such as in semantic priming (see Ober & Shenaut, 1995, for review). If early-stage DAT primarily reflects an attentional control deficit, and SD primarily reflects a semantic/lexical representational deficit, then we might expect qualitative differences in performance to emerge between these two groups.

Method

Participants

A total of 143 older adults participated in the study. Included in this sample were 67 healthy older adults (mean age = 77.3 years, mean education = 14.2 years), 70 individuals with very mild or mild DAT (mean age = 77.6 years, mean education = 14.6 years), and 6 individuals with SD (mean age = 68.8 years, mean education = 13.6 years). We refer to these 6 individuals with SD as SD1 (age = 63 years, education = 12 years), SD2 (age = 64 years, education = 12 years), SD3 (age = 69 years, education = 12 years), SD4 (age = 74 years, education = 16 years), SD5 (age = 66 years, education = 16 years), and SD6 (age = 81 years, education = 15 years). The classification of SD was based on psychometric test performance. Details of their performance on these measures are described below.

Participants were recruited from the Memory and Aging Project (MAP) participant pool at the Alzheimer's Disease Research Center (ADRC) at Washington University. These individuals were screened for disorders that could affect cognitive performance such as depression, sever hypertension, and possible reversible dementias. For inclusion or exclusion of individuals with DAT, we used the criteria established by the National Institute of Neurological and Communicative Disorders and Stroke and Alzheimer's Disease and Related Disorders Association (McKhann et al., 1984). The Washington University Clinical Dementia Rating (CDR) scale was used to assess dementia severity. The reliability of the CDR scale and the accuracy of the diagnosis by the research team have been well documented (Berg et al., 1998). According to this system, our healthy older adult sample received CDR ratings of 0.0, and those individuals with dementia were classified as having either very mild dementia (CDR 0.5, $N = 56$) or mild dementia (CDR 1.0, $N = 14$). The classification of semantic dementia was based on psychometric test performance meeting with established consensus criteria (Neary et al., 1998).

Psychometric testing

All participants underwent two hours of psychometric testing so that their language, memory, and general cognitive test performance could be assessed. Table 1 presents the means for each group on each of the psychometric measures. The Wechsler Memory Scale (WMS; Wechsler & Stone, 1973), Associates Recall and Recognition subscales (paired-associate learning), and the Logical Memory subscale (surface-level story memory) were used to assess memory. Forward and Backward Digit Span from the WMS were assessed. Participants were also assessed on Word Fluency (by naming as many words as possible that begin with P or S in a 60-s time period; Thurstone & Thurstone, 1949). General intelligence measures included the Information, Block Design, and Digit Symbol subtests of the Wechsler Adult Intelligence Scale−Revised (WAIS-R; Wechsler, 1955). Visual perceptual-motor ability was assessed via the Benton Copy Test and Trail Making Form A. In the Benton Copy Test, a geometric figure is copied; in the Trail Making Form A Test, participants connect numerically ordered dots to produce a specific pattern (Armitage, 1945). Participants were also assessed via the WMS Mental Control Test. This test evaluates the ability to generate quickly a well-rehearsed letter or digit sequence (e.g., the alphabet) in a specified time period. Participants were assessed for semantic/lexical retrieval processes in naming simple line drawings via the Boston Naming Test. Finally, knowledge of the pronunciation of words with unusual spelling-to-sound correspondences (e.g., *chamois*) was assessed via the American version of the Nelson Adult Reading Test (AMNART; Grober & Sliwinski, 1991).

A series of one-way analyses of variance (ANOVAs) with group as a between-subjects factor indicated significant effects on all measures, all ps $< .05$. Individual comparisons on the measures between groups indicated the following significant effects (all ps $< .05$): (a) healthy old versus DAT (WAIS Information, Boston Naming, Logical Memory, Associate Memory, Benton Copy, Trailmaking A, Block Design, Digit Symbol, Digit Span, Word Fluency, Mental Control, and AMNART); (b) old versus SD (WAIS Information, Boston Naming, Logical Memory, Associate Memory, Trailmaking A, Digit Symbol, Word Fluency, Mental Control, and AMNART); (c) DAT versus SD (WAIS Information, Boston Naming, Logical Memory, Associate Memory, Word Fluency, and AMNART); all other ps $> .09$.

Table 1. *Means of psychometric measures as a function of participant group*

	Healthy old	*DAT*	*SD*
WAIS information	21.77 (4.64)	16.34 (6.26)	6.0 (3.35)
Boston naming	55.68 (5.0)	47.10 (12.46)	14.83 (11.67)
Logical memory	10.57 (3.82)	5.71 (4.03)	1.42 (1.24)
Associate memory	15.25 (3.77)	10.76 (3.98)	4.50 (1.27)
Benton copy	9.86 (0.46)	9.24 (1.34)	9.83 (0.41)
Trailmaking A	36.17 (11.92)	58.37 (31.66)	47.83 (13.08)
Block design	31.97 (8.71)	24.03 (10.83)	27.33 (9.35)
Digit symbol	49.09 (10.65)	35.61 (13.58)	36.00 (8.90)
Digit span	11.55 (2.15)	10.25 (2.17)	10.00 (1.55)
Word fluency	31.52 (11.57)	24.60 (9.20)	12.00 (6.78)
Mental control	7.58 (1.80)	6.49 (2.38)	5.17 (2.79)
AMNART	35.21 (7.25)	28.93 (10.53)	9.83 (9.22)

Note: Standard deviations in parentheses. DAT = dementia of the Alzheimer's type. SD = semantic dementia. WAIS = Wechsler Adult Intelligence Scale. AMNART = American version of the Nelson Adult Reading Test.

Classification of semantic dementia

The neuropsychological profiles of the 6 SD participants are described in detail elsewhere (Gold et al., 2005). Briefly, SD individuals were initially identified as having probable semantic impairment via disproportionate impairment on semantic compared to nonsemantic psychometric test performance (Cortese et al., 2003). A neuropsychological battery was then administered to identify those individuals meeting original (Hodges, Patterson, Oxbury, & Funnell, 1992) and consensus (Neary et al., 1998) inclusion and exclusion criteria for SD—namely, presentation with impairment in semantic memory causing anomia and deficits of spoken and written single-word comprehension, a reading pattern of surface dyslexia, and impoverished knowledge about objects and/or people with relative sparing of phonological and syntactic[3] components of speech output, and perceptual and nonverbal problem-solving skills. The neuropsychological battery included a set of semantic tests developed by the Cambridge group for identification of SD (e.g., Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000; Hodges et al., 1992). Psychometric scores are summarized in Table 2.

Structural magnetic resonance imaging

Structural magnetic resonance imaging (MRI) was performed as part of an ongoing protocol examining changes in brain structure associated with ageing. In particular, MRI images of participants meeting neuropsychological consensus criteria for SD were examined for the presence of temporal pole atrophy characteristic of SD to cross-validate clinical classification. MRI was performed on a Siemens 1.5 T Vision System (Erlangen, Germany). Between 2 and 4 high-resolution ($1 \times 1 \times 1.25$-mm) T1-weighted MP-RAGE scans were acquired per participant (TR = 9.7 ms, TE = 4 ms, flip angle = 10°, TI = 20 ms, TD = 200 ms). Scans were motion corrected and averaged, yielding a single image volume with high contrast-to-noise ratio, enabling quantitative characterization. All neuropsychological testing and experiments were conducted within 6 months of MRI scans.

Figure 1 presents MR images of the 6 SD patients, taken from Gold et al. (2005). Reduced volume in the temporal pole region is present in all SD participants to varying degrees, corroborating the neuropsychological classification. In our previous quantitative analysis of MRI images,

[3] For evidence of independence between lexical syntax and semantics in SD, see Garrard, Carroll, Vinson, and Vigliocco (2004).

Table 2. *Psychometric scores used in SD classification*

Test	Maximum score	Control[a]	DAT[b]	SD[c]	Patient SD1	SD2	SD3	SD4	SD5	SD6
Boston naming	60	55.4 (3.7)	48.4 (11.0)	14.8 (11.7)	5	6	8	16	36	18
Animal fluency		22.2 (4.3)	14.3 (4.6)	5.7 (2.0)	7	8	5	3	7	4
AMNART	45	33.4 (6.8)	32.0 (4.1)	11.8 (8.8)	0	5	7	11	27	9
Category fluency		82.2 (15.4)	58.4 (20.5)	19.0 (7.1)	na	na	24	14	36	na
Synonym judgement	96	89.8 (5.0)	86.8 (6.3)	66.0 (14.2)	na	55	61	na	82	na
Word-to-picture matching	64	63.8 (0.4)	62.8 (1.5)	44.3 (17.5)	13	57	50	42	63	41
Category sort	128	125.6 (1.7)	124.2 (2.8)	116.6 (16.1)	116	110	118	118	121	na
Pyramids and palm trees										
pictures	52	50.9 (1.1)	49.8 (2.0)	38.8 (8.7)	26	48	36	35	49	39
Cookie theft picture	6	5.8 (0.3)	5.9 (0.2)	5.9 (0.1)	6	6	5.8	6	6	6
Auditory comprehension	15	14.9 (0.3)	14.8 (0.5)	12.3 (1.5)	10	11	14	12	12	14
Benton copy	10	9.2 (1.8)	8.3 (3.5)	9.8 (0.4)	10	9	10	10	10	10
WAIS block design	48	29.6 (9.0)	23.9 (13.0)	27.2 (10.4)	28	20	44	18	30	24
Raven's matrices	36	30.3 (5.2)	23.6 (5.8)	30.2 (3.1)	32	31	34	29	25	30
VOSP										
Screening test	20	19.5 (.0.8)	19.5 (0.7)	19.0 (1.8)	na	16	20	20	20	20
Dot counting	10	9.6 (0.7)	9.9 (0.3)	10.0 (0.0)	na	10	10	10	10	10
Position discrimination	20	19.1 (2.8)	19.9 (0.3)	20.0 (0.0)	na	20	20	20	20	20
Number location	10	9.7 (0.6)	9.4 (0.7)	8.5 (0.9)	na	7	9	9	9	9
Cube analysis	10	9.7 (0.6)	8.9 (1.0)	9.0 (1.0)	na	9	10	9	8	10
Digit span										
Forward		6.6 (1.2)	5.7 (1.1)	6.2 (0.8)	7	5	7	6	6	6
Backward		5.1 (1.0)	3.8 (1.6)	4.3 (0.8)	4	4	6	4	4	4
WAIS digit symbol	90	47.9 (9.3)	31.8 (16.9)	39.8 (1.3)	41	39	41	39	38	41
Trails A	180	36.2 (11.9)	61.9 (44.8)	47.8 (13.1)	58	38	37	65	34	55
Trails B	180	106.2 (37.8)	144.8 (44.8)	122.0 (25.7)	144	115	85	114	158	116

Note: Standard deviations are in parentheses. DAT = dementia of the Alzheimer's type. AMNART = American Version of Nelson Adult Reading Test. Raven's Matrices = Raven's Coloured Progressive Matrices (Raven, 1965). WAIS = Wechsler Adult Intelligence Sacle. VOSP = Visual Object and Space Perception battery. na = not available. The data are from age matched groups of healthy controls and DAT patients.
[a]$n = 14$. [b]$n = 10$. [c]$n = 6$.

significantly reduced grey matter thickness was observed in the left temporal pole of the SD group compared to that in an AD group of similar global dementia severity (Gold et al., 2005). In addition to temporal pole atrophy, several of the SD participants show additional hippocampus atrophy, consistent with recent results (Boxer et al., 2003; Galton et al., 2001).

Materials

A total of 34 verbs were used in the study (see Appendix for a listing of each of the verbs, their present tense, past tense, number of friends, number of enemies, frequency of friends, frequency of enemies, and the accuracy rates for each of the three groups). Nine verbs were selected for each of the conditions except for the irregular consistent condition, which consisted of seven verbs. Regular verbs were defined as those that follow the add -ed rule for their past-tense form, and irregular verbs as those that do not follow the add -ed rule for their past-tense form. Both orthography and phonology were used to determine consistency because we have no a priori assumptions about the relative importance of orthography and phonology and because stimuli in the experiment were to be presented visually. Neighbours of the target verb shared the

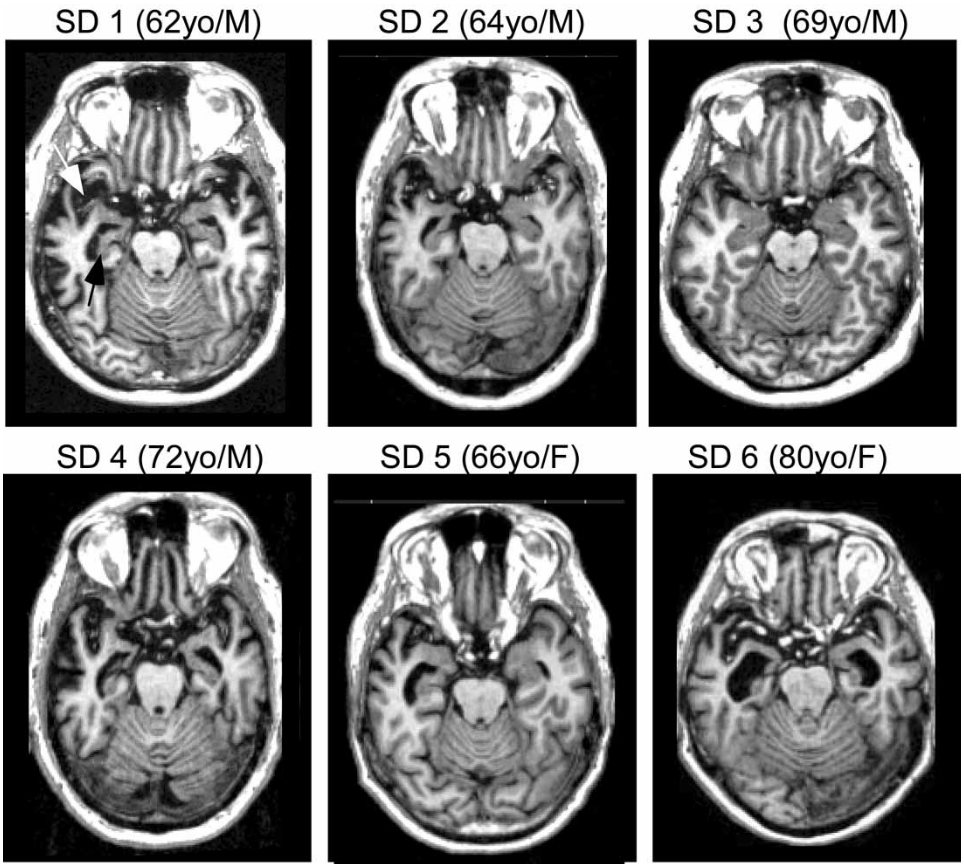

Figure 1. *Magnetic resonance images of the 6 semantic dementia (SD) participants showing reduced brain volumes in the temporal pole region. Images are labelled at the top with age in years old (yo) and sex (male, M; female, F). The left side of the brain is on the left side of the image (neurological view). The temporal pole (white arrow) and hippocampal (black arrow) regions are referenced on the image of SD1. In addition to hallmark temporal pole atrophy, several SD participants (in particular SD6) show additional atrophy of medial temporal lobes at or near the hippocampus.*

present-tense orthographic and phonological rime. Friends shared the present-tense orthographic and phonological rime as well as the conjugated form, and enemies shared the present-tense orthographic and phonological rime but had a different conjugated form. Based on types (i.e., not tokens), consistent verbs were defined as verbs that had more friends (5.0) than enemies (1.6), $F(1, 30) = 24.94$, $p < .001$, $MSE = 3.0$, and inconsistent verbs were defined as those that had more enemies (4.9) than friends (1.9), $F(1, 30) = 19.03$, $p < .001$, $MSE = 4.63$. Regular verbs tended to have more friends than did irregular verbs (4.1 vs. 2.5), $F(1, 30) = 5.97$, $p < .05$, $MSE = 3.0$, but there was no interaction between regularity and consistency regarding the number of friends, $F < 1$. The number of enemies did not differ by regularity nor was there an interaction between regularity and consistency, both Fs < 1. The mean frequency of the verbs in their present-tense forms was 2.9 per million ($SD = 4.3$) and in their past-tense forms was 2.0 per million ($SD = 1.9$; Baayen, Piepenbrock, & van Rijn, 1993), and this did not differ by condition, all Fs < 1. The frequency of friends and enemies listed in the Appendix was based on the past tense of the verbs in the Baayen et al. (1993) norms.

Procedure
Participants were presented with two sentences. The first sentence included the present tense of the verb:

Everyday I ding the bell.

The participant read aloud the sentence. Immediately after the sentence was read, the experimenter pressed the space bar. The first sentence remained in view as the second sentence was presented just below it, and the participant read it as quickly and accurately as possible while completing the blank with the appropriate past-tense form:

Yesterday, I_______the bell.

The experimenter then coded the response as correct, regularization error, consistency error, or other error. In cases where multiple responses were provided, the first response was coded. Reading errors were not common. In the rare circumstance where a reading error occurred in the first sentence, it was corrected by the experimenter and reread by the participant prior to the presentation of the second sentence. Reading errors on the second sentence were very rare.

Design
The experiment consisted of three factors: group (old, DAT, and SD), regularity (regular, irregular), and consistency (consistent, inconsistent). In addition, the summed frequency of friends and the summed frequency of enemies were assessed as covariates in the item analyses. Proportion correct served as the main dependent variable. Other dependent variables included: (a) proportion of regularization errors, (b) proportion of analogy errors, and (c) proportion of other errors.

Results and discussion

Mixed factor and repeated measures ANOVAs were used to analyse the data. In addition, for clarity and organization, interpretations of the results are provided within each subsection. More general theoretical implications are considered in the General Discussion.

Unless otherwise noted, all initial analyses involving group included healthy older adults, individuals with DAT, and individuals with SD. As described below, when reliable effects of group or interactions with group were obtained, subsequent individual group analyses were conducted (e.g., old vs. DAT; old vs. SD; SD vs. DAT).[4] We note that although there are only 6 SD individuals, their pattern of data is consistent and reliable. Data from the individual SD patients can be found in Table 3.[5] In all analyses that follow, results are significant at an alpha level of .05 unless otherwise noted. Also, separate subject (F_s) and item (F_i; Clark, 1973) analyses were conducted for the proportion of correct responses and regularization errors. Regularity and consistency were within-subjects factors in the analyses by subjects and between-items factors in the analyses by items. Participant group was a between-subjects factor in the analyses by subjects and a within-subjects factor in the analyses by items. In the analyses by items, the summed frequency of friends and the summed frequency of enemies were included as covariates. In order for completeness, we include all of the results from the overall ANOVAs in Table 4. Other analyses appear in the text to follow.

Proportion of correct responses
The proportion of correct responses was the dependent variable of greatest interest, and the pattern of data here is the most revealing. The proportion of correct responses by verb type across

[4] In all simple effects analyses involving group, we employed a modified Scheffe test for mixed designs. In these analyses, the mean square error from the omnibus analysis involving all three groups was used for each specific computation, and the degrees of freedom were based on the two groups combined.

[5] SD1 received the regular inconsistent verbs *king* (e.g., *he kinged his checkers*) and *breeze* rather than *ding* and *sneeze*, and he did not receive the irregular inconsistent verbs *slay* and *fly*.

Table 3. *Individual data from semantic dementia patients for each condition of verbs*

	Regular						Irregular							
	Consistent			Inconsistent			Consistent				Inconsistent			
Patient	*All*	*Anal.*	*Other*	*All*	*Anal.*	*Other*	*All*	*Anal.*	*Other*	*Reg.*	*All*	*Anal.*	*Other*	*Reg.*
SD1	.56	.11	.33	.22	.44	.33	.00	.00	.71	.29	.29	.00	.43	.29
SD2	1.0	.00	.00	.89	.00	.11	.00	.00	.00	1.0	.44	.00	.11	.44
SD3	.56	.00	.44	.11	.00	.89	.43	.00	.57	.00	.33	.00	.67	.00
SD4	.78	.00	.22	.33	.22	.44	.29	.00	.43	.29	.44	.00	.00	.56
SD5	1.0	.00	.00	.89	.00	.21	.86	.00	.00	.14	.56	.00	.11	.33
SD6	.89	.00	.11	.44	.22	.33	.71	.00	.14	.14	.67	.00	.22	.11

Note: All = overall accuracy; Anal. = analogy errors; Other = other errors; Reg. = regularization errors.

the participant groups is presented in Table 5. The results indicate that regularity effects were substantial, whereas the effect of consistency was relatively smaller for both regular and irregular verbs. However, the item analyses revealed, that, in terms of consistency, the frequency of enemies was a significant predictor of performance in all groups. Specifically, verbs associated with a high summed frequency of enemies were responded to less accurately than verbs associated with a low summed frequency of enemies.

As shown in Tables 4 and 5, there were also substantial group differences. These included the following: (a) DAT individuals were more affected by the frequency of enemies than healthy older adults (as reflected by the interaction between group and frequency of enemies); (b) DAT individuals did not display a larger regularity effect than that for healthy older adults; and (c) compared to both healthy older adults and individuals with DAT, SD individuals were much more disrupted by regular inconsistent verbs and both types of irregular verb. As noted, individual SD data are presented in Table 3.

Qualitative versus quantitative differences across groups. One might argue that the different pattern observed in DAT and SD reflects the difference in the degree of impairment rather than a qualitative difference. Specifically, it might be argued that both groups would show the same pattern of performance if they were impaired to the same degree. For example, our DAT sample was near ceiling for regular consistent verbs whereas our SD sample was not. Therefore, it is possible that if DAT individuals were less accurate for regular consistent verbs, they too would show the same overall pattern of performance found in SD. This outcome would greatly compromise the claim that there are qualitative differences between DAT and SD. To address this possibility, we separated 17 individuals with DAT who were less than 100% accurate on regular consistent verbs. As can be seen in Table 6, the pattern of performance found in this group of DAT individuals is still strikingly different from the SD sample despite being equated for performance on regular consistent verbs. In fact, even with this small sample of participants, the three-way interaction between regularity, consistency, and group was significant, $F_s(1, 19) = 6.43$, $MSE = 0.016$.

We also attempted to address the same issue in the healthy ageing versus DAT analyses. Hence, we selected all individuals who performed at 100% correct in both groups in the regular consistent condition. As shown in the bottom half of Table 6, there still appears to be a difference in the consistency effect. In fact, the results of the ANOVA on these individuals yielded a highly reliable group by consistency interaction, $F_s(1, 118) = 9.01$, $MSE = 0.006$. Also, the main effects of group, $F_s(1, 118) = 7.34$, $MSE = 0.014$, regularity, $F_s(1, 118) = 151.42$, $MSE =$

Table 4. *The results of the statistical analyses conducted on the proportion of correct responses*

	Subjects				Items			
	df_s	F_s	p	MSE	df_i	F_i	p	MSE
Omnibus analyses: all groups								
Group	2, 140	37.06*		.049	2, 56	76.42*		.010
Regularity	1, 140	59.40*		.017	1, 28	11.31*		.045
Consistency	1, 140	31.49*		.008		1.19	.29	
Frequency of friends						<1		
Frequency of enemies					1, 28	6.96*		.045
Regularity × Consistency	1, 140	29.02*		.009	1, 28	4.57*		.045
Group × Regularity	2, 140	2.00	.14		2, 56	3.07	.06	.010
Group × Consistency	2, 140	5.23*		.008		<1		
Group × Regularity × Consistency	2, 140	9.80*		.009	2, 56	9.56*		.010
Group × Frequency of friends						<1		
Group × Frequency of enemies					2, 56	1.79	.18	
DAT analyses: old vs. DAT								
Group	1, 135	16.12*		.044	1, 28	28.01*		.001
Regularity	1, 135	117.00*		.014	1, 28	6.70*		.028
Consistency	1, 135	43.58*		.007		<1		
Frequency of friends						<1		
Frequency of enemies					1, 28	5.05*		.028
Regularity × Consistency	1, 135	5.08*		.009		<1		
Group × Regularity		<1				<1		
Group × Consistency	1, 135	6.77*		.007	1, 28	1.46	.24	
Consistency: old	1, 135	3.75	.09					
Consistency: DAT	1, 135	15.00*						
Group × Regularity × Consistency		<1			1, 28	2.38	.13	
Group × Frequency of friends						<1		
Group × Frequency of enemies					1, 28	13.88*		.001
Frequency of enemies: old					1, 28	2.16	.15	
Frequency of enemies: DAT					1, 28	8.20*		.016
SD analyses: SD vs. old								
Group	1, 71	134.44*		.025	1, 28	87.24*		.016
Regularity	1, 71	37.93*		.016	1, 28	12.56*		.033
Consistency	1, 71	21.11*		.006	1, 28	1.26	.27	
Frequency of friends						<1		
Frequency of enemies					1, 28	5.46*		.033
Regularity × Consistency	1, 71	31.97*		.007	1, 28	6.54*		.033
Group × Regularity	1, 71	4.22*		.016	1, 28	3.26	.08	.016
Regularity: old	1, 71	3.92*		.017				
Regularity: SD	1, 71	14.27*		.017				
Group × Consistency	1, 71	8.26*		.006	1, 28	1.23	.28	
Consistency: old		<1						
Consistency: SD	1, 71	11.66*		.017				
Group × Regularity × Consistency	1, 71	24.81*		.007	1, 28	10.65*		.016
Regularity × Consistency: old		<1				<1		
Regularity × Consistency: SD	1, 71	93.07*		.009	1, 28	10.82*		.035
Consistency: regular verbs	1, 71	62.66*		.009	1, 14	15.20*		.028
Consistency: irregular verbs		<1			1, 14	1.52	.24	
Group × Frequency of friends						<1		
Group × Frequency of enemies					1, 28	2.18	.15	
SD vs. DAT analyses								
Group	1, 74	28.32*		.080	1, 28	70.21*		.013

(*Continued overleaf*)

Table 4. *(Continued)*

	Subjects				*Items*			
	df_s	F_s	p	*MSE*	df_i	F_i	p	*MSE*
Regularity	1, 74	27.78*		.022	1, 28	11.49*		.038
Consistency	1, 74	18.66*		.011	1, 28	1.63	.21	
Frequency of friends						<1		
Frequency of enemies					1, 28	8.33*		.038
Regularity × Consistency	1, 74	21.34*		.012	1, 28	7.18*		.038
Group × Regularity	1, 74	2.82	.10		1, 28	3.27	.08	
Group × Consistency	1, 74	1.76	.19			<1		
Group × Regularity × Consistency	1, 74	13.07*		.012	1, 28	9.15*		.013
Regularity × Consistency: DAT	1, 74	1.53	.22					
Regularity × Consistency: SD	1, 74	93.39*		.009	1, 28	10.82*		.035
Consistency: regular verbs	1, 74	62.87*		.009	1, 14	15.20*		.028
Consistency: irregular verbs		<1			1, 14	1.52	.24	
Group × Frequency of friends						<.1		
Group × Frequency of enemies						<1		
Regularization errors Omnibus analyses: all groups								
Group	2, 140	14.58*		.022	2, 24	17.02*		.005
Consistency	1, 140	2.05	.154			<1		
Group × Consistency		<1			2, 24	1.25	.31	
Frequency of Friends						<1		
Frequency of Enemies					1, 12	9.79*		.022
Group × Frequency of friends					2, 24	1.82	.18	
Group × Frequency of enemies					2, 24	1.43	.26	
DAT analyses: old vs. DAT								
Group	1, 135	12.08*		.018	1, 12	6.43*		.001
Consistency	1, 135	22.99*		.009		<1		
Group × Consistency		<1				<1		
Frequency of friends						<1		
Frequency of enemies					1, 12	14.38*		.012
Group × Frequency of friends						<1		
Group × Frequency of enemies					1, 12	10.42*		
Frequency of Enemies: old					1, 12	8.81*		.005
Frequency of Enemies: DAT					1, 12	17.20*		.008
SD analyses: SD vs. old								
Group	1, 71	25.39*		.021	1, 12	19.91*		.008
Consistency					<1	<1		
Group × Consistency	1, 71	1.43	.24		1, 12	1.33	.27	
Frequency of friends						<1		
Frequency of enemies					1, 12	5.74*		.017
Group × Frequency of friends					1, 12	1.55	.24	
Group × Frequency of enemies						<.1		
SD vs. DAT analyses								
Group	1, 74	9.94*		.030	1, 12	15.37*		.007
Consistency		<1				<1		
Group × Consistency	1, 74	1.21	.28		1, 12	1.37	.27	
Frequency of friends						<1		
Frequency of enemies					1, 12	8.35*		.022
Group × Frequency of friends					1, 12	2.48	.14	
Group × Frequency of enemies					1, 12	1.49	.25	

Note: DAT = dementia of the Alzheimer's type. SD = semantic dementia.
* F value significant at $p < .05$.

Table 5. *Proportion of correct responses by verb type for each participant group*

Participant group	*n*	Regular: Consistent	Regular: Inconsistent	Irregular: Consistent	Irregular: Inconsistent
Healthy old	67	1.0 (.00)	.96 (.01)	.88 (.02)	.86 (.01)
DAT	70	.95 (.02)	.86 (.02)	.81 (.02)	.77 (.02)
SD	6	.80 (.08)	.48 (.14)	.39 (.15)	.46 (.06)

Note: Standard errors are in parentheses. DAT = dementia of the Alzheimer's type. SD = semantic dementia.

0.007, and consistency, $F_s(1, 118) = 50.62$, $MSE = 0.006$, remained significant, and no other effects were significant, all ps $> .16$.

The results involving the proportion of correct responses are relatively clear. First, as predicted by the models, because of the large proportion of regular verbs in English, one expected the large effect of regularity. Second, as predicted by the models, one expected that consistency would have an influence on the proportion of correct responses, and this outcome was also obtained. Third, the item analyses revealed that consistency is realized in terms of the summed frequency of enemies. The summed frequency of friends was unrelated to accuracy. However, it is important to note that the failure to observe a frequency of friends effect may simply be due to the restriction of range on this variable. Specifically, the standard deviation for the summed frequency of friends was 29.3 compared to 109.2 for the summed frequency of enemies.

Importantly, regularity and consistency interacted with participant groups in interesting and important ways. Individuals with DAT displayed larger consistency effects (based on the summed frequency of enemies) than did healthy older adults. This outcome suggests that individuals with DAT have difficulty selecting the appropriate response when that response has a phonology that is also associated with alternative responses (e.g., inconsistent verbs). Furthermore, the higher the frequency of enemies, the more difficult it is for individuals with DAT to select the appropriate response. Interestingly, the regularity effect did not increase with DAT. This indicates that even though irregular verbs may be associated with an alternative past-tense verb form, this only produces increases in error rates relative to healthy older adults when the verbs also have a high summed frequency of enemies. By itself, this pattern could be viewed as consistent with either an attentional selection deficit or a lexical/semantic deficit.

Interestingly, the pattern observed in DAT is qualitatively different from that observed in SD. Individuals with SD are more disrupted than individuals with DAT for both types of irregular verbs as well as regular inconsistent verbs, above and beyond the summed frequency of friends and enemies. According to the L&R model, a semantic impairment does not necessarily mean that lexical

Table 6. *Overall accuracy across condition by DAT and SD and by DAT and healthy older adults when matched for accuracy on regular consistent verbs*

Participant group	*n*	Regular: Consistent	Regular: Inconsistent	Irregular: Consistent	Irregular: Inconsistent
DAT	17	.80 (.05)	.67 (.02)	.69 (.02)	.71 (.02)
SD	6	.80 (.08)	.48 (.14)	.39 (.15)	.46 (.06)
Difference		.00	.19	.30	.25
Healthy old	67	1.0 (.00)	.96 (.01)	.88 (.02)	.86 (.01)
DAT	53	1.0 (.00)	.92 (.01)	.86 (.02)	.79 (.02)
Difference		.00	.04	.02	.07

Note: Standard errors are in parentheses. DAT = dementia of the Alzheimer's type. SD = semantic dementia.

forms have been affected. However, assuming that relatively proximal brain areas are tied to these two levels of representation, impairment in one area may produce impairment in the other area. Therefore, one might a priori expect that individuals with SD should be disrupted for irregular and inconsistent verbs. Performance on irregular verbs would be affected because lexical forms must be accessed for correct responses. Regular inconsistent verbs could also be affected if the lexical representation for the target verb becomes degraded, and neighbours with similar present-tense forms contribute more strongly than usual to the response. In contrast, the PDP model predicts that irregular and inconsistent verbs should be affected, but that the disruption should be graded. Specifically, damage to the semantic system should produce the largest deficit to irregular inconsistent verbs, and a smaller deficit should be observed for irregular consistent and regular consistent verbs. This pattern was not found in the present results.

Regularization errors

The mean number of regularization errors (e.g., *singed* for *sang*) as a function of group are reported in Table 7. The results from these analyses (see Table 4) are also quite clear. The proportion of regularization errors increased with DAT, increased with SD, and was greater in SD than in DAT. In addition, the item analyses indicated that the frequency of enemies was related to regularization errors. Regarding the pattern of data observed in DAT, one might expect that if DAT involves an attentional control deficit then regularization errors would increase, and they did. Furthermore, one might expect that if DAT individuals have difficulty controlling activated competitors then regularization errors in this population might be more influenced by the frequency of enemies than would those in healthy older adults, and this occurred as well. This appears akin to the word intrusion rates that one finds in Stroop performance in early-stage DAT (see Spieler, Balota, & Faust, 1996). For SD individuals, regularization errors increase dramatically, and this was not dependent upon the frequency of enemies, again suggesting a different locus of the effect.

Analogy errors

The mean proportion of analogy errors (e.g., "dang" for *ding*) by condition is presented in Table 8. Formal analyses were not conducted on analogy errors because analogy errors were quite low for most groups (less than .02 in all conditions). However, it is important to note that individuals with SD committed analogy errors relatively often for regular inconsistent verbs (.15). This outcome is consistent with the idea that in healthy language processors, regular inconsistent verbs receive support from semantics. When damage occurs to semantic memory, as in SD, there is marked disruption for regular inconsistent verbs. This interpretation lends itself quite well to the PDP model. Specifically, the PDP model posits that semantic and phonological systems are interactive, and inconsistent verbs will

Table 7. *Proportion of regularization errors across condition by participant group*

		Irregular	
Participant group	*n*	*Consistent*	*Inconsistent*
Healthy old	67	.05 (.01)	.10 (.01)
DAT	70	.11 (.02)	.16 (.02)
SD	6	.31 (.15)	.29 (.09)

Note: Standard errors are in parentheses. DAT = dementia of the Alzheimer's type. SD = semantic dementia.

Table 8. *Proportion of analogy errors across condition by participant group*

		Regular		*Irregular*	
Participant group	*n*	*Consistent*	*Inconsistent*	*Consistent*	*Inconsistent*
Healthy old	67	.00 (.00)	.01 (.01)	.00 (.02)	.00 (.01)
DAT	70	.00 (.02)	.01 (.02)	.00 (.02)	.01 (.02)
SD	6	.02 (.02)	.15 (.07)	.00 (.00)	.00 (.00)

Note: Standard errors are in parentheses. DAT = dementia of the Alzheimer's type. SD = semantic dementia.

Table 9. *Proportion of other errors across condition by participant group*

Participant group	*n*	*Regular*		*Irregular*	
		Consistent	*Inconsistent*	*Consistent*	*Inconsistent*
Healthy old	67	.00 (.00)	.03 (.01)	.07 (.01)	.03 (.01)
DAT	70	.05 (.02)	.12 (.02)	.08 (.01)	.06 (.01)
SD	6	.18 (.07)	.39 (.12)	.31 (.12)	.25 (.10)

Note: Standard errors are in parentheses. DAT = dementia of the Alzheimer's type. SD = semantic dementia.

rely more on semantics than will consistent verbs. In terms of the L&R model, one might posit that the stem of the target word has been degraded, and hence the neighbours contribute more to the response.

Other errors

Other errors as a function of group are reported in Table 9. Other errors usually consisted of repeating the verb in its present tense, replacing the verb with a similar verb (*creep–snuck*) or some variation of a regularization or analogy error (e.g., *ding–danged, freeze–frozed*). Formal analyses are not reported here because they add little to the analyses conducted on overall accuracy and are theoretically less informative. As expected, we find that these errors increase in DAT and SD. For healthy older adults and individuals with DAT, these errors are common for regular inconsistent verbs, and they are more common for irregular consistent verbs than for irregular inconsistent verbs. In addition, individuals with SD produce most of their other errors in the three conditions in which they are least accurate.

GENERAL DISCUSSION

The results of this study provide important information regarding performance in the past-tense verb generation task and the theoretical perspectives designed to explain verb processing. As expected, our participants were more accurate in generating the past tense for regular than irregular verbs. In addition, we found that participants were more accurate at generating the past tense of consistent verbs than that of inconsistent verbs. Furthermore, we found that the consistency effect as defined by the frequency of enemies increased with DAT. Also, we found that individuals with SD were relatively equally disrupted by irregularity and inconsistency—that is, performance was markedly impaired in the regular inconsistent, irregular consistent, and irregular inconsistent conditions, compared to the regular consistent condition. Moreover, these results were not due to overall differences in performance because when subjects were matched on regular consistent condition performance, the differences still held.

The L&R model (Pinker, 1999) and the PDP model (Joanisse & Seidenberg, 1999) provide useful frameworks to interpret our data. Both models can accommodate regularity and consistency effects, and the pattern of data observed in SD and DAT can be interpreted in terms of the models. We now turn to a discussion of each model.

The L&R model

The L&R model (Pinker, 1999) can easily account for the main effect of regularity in overall accuracy. The verbs employed in the current study were low-frequency verbs, and one could reasonably expect that the add -ed rule would be implemented some of the time for irregular verbs. In addition, the L&R model can accommodate consistency effects by proposing that neighbours of a target verb become partially activated during processing. Friends facilitate processing, and enemies hinder the processing of the target verb.

Regarding DAT, if DAT involves a semantic deficit, this should produce a greater disruption for inconsistent (i.e., verbs associated with a high summed frequency of enemies) than consistent verbs, and this is what is observed. However, given that the pattern observed in DAT is qualitatively different than that observed in SD—a group that by definition has disruption in semantic/lexical representations—it is difficult to claim that deficits in verb processing have a semantic basis in DAT.

Considering SD, the L&R model predicts that impairment to semantic memory may also be accompanied by damage to lexical forms. The verbs employed in the present study are low-frequency verbs and, thus, are the most vulnerable to degradation. When lexical forms become lost or degraded, irregular-verb processing will suffer, and the influence of neighbours may increase. Of course, in some cases, the neighbours themselves may become degraded and have less of an influence. However, for most of the verbs employed in the present study, the summed frequencies of the neighbours exceeds that of the target word.

The PDP model

The PDP model (Joanisse & Seidenberg, 1999) accurately predicted main effects of regularity and frequency of enemies in overall accuracy. These main effects arise naturally in the model due to the strength of connections that are formed during learning. Specifically, regular and consistent verbs form stronger connections than do irregular and inconsistent verbs, and accuracy reflects the strength of connections in the network.

As previously stated, the fact that the pattern observed in DAT is qualitatively different from that observed in SD suggests that it is unlikely that deficits in verb processing have a semantic basis in DAT. The pattern observed in SD is close to that predicted by the PDP model. According to the PDP model, one would expect that regular inconsistent, irregular consistent, and irregular inconsistent verbs would all be negatively affected by SD, and they were. However, one might expect that the pattern would be more graded than that observed. Specifically, a priori, it would appear that the PDP model predicts that irregular inconsistent verbs would be more affected than irregular consistent and regular inconsistent verbs. Furthermore, it is clear that SD involves a disruption that goes beyond the summed frequencies of friends and enemies. Both the number of verb neighbours and the frequency of occurrence should influence the model's performance. Friends will share weighted connections, and enemies will not, and so neighbourhood effects naturally arise in the model. However, it is important to note that, given the small sample of SD patients, one must be careful not to overinterpret these results.[6]

DAT versus SD: The role of attentional control

The clear qualitative difference in performance of the DAT and the SD individuals is illuminating. As noted earlier, we have argued that, as in other cognitive tasks, an attentional control system must select and inhibit particular forms prior to making responses in language tasks (Balota et al., 1999). Moreover, we have argued that DAT produces a deficit in this attentional control system. The main hypothesis from this perspective is that when considering performance in early-stage DAT, one should not rely simply on semantic deficits, but rather one should consider the attentional control systems that select from such representations. The larger consistency effect observed in overall accuracy in DAT is consistent with this view. Inconsistent verbs are more likely to activate competing responses that need to be inhibited (i.e., selected against). A breakdown in this process leads to an incorrect response. Interestingly, we demonstrate with our design that individuals with DAT do not really exhibit an increase in the regularity effect per se. Previous research (e.g., Ullman et al., 1997) has sampled regular verbs and irregular verbs from essentially two of the four cells employed in the present study, and this research has not assessed the frequency of verb neighbours. Specifically, previous research has examined regular verbs

[6] Although the PDP perspective would appear to predict the graded effects, as indicated, it is possible that differences in the strength of the semantic and phonological representations and/or connections could capture these results, and so, ultimately, quantitative predictions from this framework are necessary to directly test the predictions.

that are consistent and irregular verbs that are inconsistent, and hence regularity has been confounded with consistency. If we examine only the regular consistent verb and irregular inconsistent verb cells in our study, we find that overall accuracy in DAT drops by .05 for regular verbs and nearly twice that for irregular verbs (.09). However, through our design, we have determined that this difference between healthy older adults and DAT is not due to regularity but to the frequency of enemies. Because individuals with DAT exhibit a larger consistency effect than healthy older adults, this produces the illusion of an increase in the regularity effect in studies that only examine the two verb types. In our study, when consistency is crossed with regularity, we find that while the effect of enemies is larger in DAT than healthy older adults, the regularity effect remains constant.

Again, we note that previous accounts have proposed that decreases in accuracy for irregular verbs in DAT are due to semantic deficits (e.g., Joanisse & Seidenberg, 1999; Ullman et al., 1997). The extant literature across a variety of domains suggests that the language deficits that arise in early-stage DAT are in large part driven from a deficient attentional mechanism instead of only a deterioration in semantic representations. For example, under conditions less demanding to attention, individuals with DAT exhibit the same degree of associate/semantic priming as that for healthy older adults (Balota & Duchek, 1991; see Ober & Shenault, 1995, for a review). In addition, when spelling homophones, individuals with DAT use semantic information to the same degree as healthy older adults while individuals with a semantic impairment rely heavily on phonological information (Cortese et al., 2003). Also, we note that individuals with SD display a qualitatively different pattern in verb processing in the current study. Therefore, it is unlikely that verb-processing deficits in DAT are due to a problem with semantic memory.

Summary and conclusions

The present study crossed regularity and consistency and assessed the summed frequency of friends and enemies in a past-tense verb generation task in healthy older adults, individuals with DAT, and individuals with SD. We found robust regularity and frequency of enemies effects in overall accuracy. The pattern of overall accuracy between DAT and SD was qualitatively different. This difference in results across these two groups of individuals corresponds well with a focal semantic deficit in SD and with the contribution of an attentional control deficit in DAT.

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APPENDIX

The present and past tense, number and summed frequency of friends and enemies, and overall accuracy by each group for each verb used in the present study

			Number		*Frequency*		*Accuracy*	
Verb type	*Present–past tense*	*Friends*	*Enemies*	*Friends*	*Enemies*	*Old*	*DAT*	*SD*
Regular consistent	match–matched	6	1	6	22	1.0	.99	1.0
	land–landed	6	1	13	42	.99	.86	.67
	leak–leaked	7	2	3	29	1.0	.93	.67
	mow–mowed	10	4	26	149	1.0	.97	.83
	sneeze–sneezed	2	1	2	1	1.0	.96	.67
	clean–cleaned	4	0	9	0	1.0	.99	1.0
	smell–smelled	6	2	7	109	.97	.96	1.0

(*Continued overleaf*)

Appendix *(Continued)*

			Number		*Frequency*		*Accuracy*	
Verb type	*Present–past tense*	*Friends*	*Enemies*	*Friends*	*Enemies*	*Old*	*DAT*	*SD*
	trim–trimmed	5	1	1	2	1.0	.96	.83
	spy–spied	7	1	47	6	1.0	.99	.67
Regular inconsistent	blind–blinded	2	4	2	102	.99	.90	.67
	link–linked	3	5	7	13	1.0	.94	.50
	beep–beeped	3	5	0	59	.99	.94	.17
	ding–dinged	2	9	0	81	.72	.51	.33
	weed–weeded	3	4	31	12	1.0	.90	.50
	heave–heaved	1	2	1	84	.93	.81	.33
	fit–fitted	2	4	3	56	1.0	.91	.67
	tend–tended	4	4	8	67	1.0	.90	.50
	cite–cited	1	4	1	34	.99	.91	.67
Irregular consistent	creep–crept	5	3	59	0	.90	.73	.17
	swear–swore	4	0	22	0	.91	.80	.17
	sting–stung	8	3	17	64	.99	.93	.33
	bleed–bled	4	3	12	31	1.0	.96	.67
	lend–lent	4	4	67	8	.60	.59	.33
	hurt–hurt	1	0	6	0	.99	.94	.50
	burst–burst	1	0	3	0	.81	.79	.50
Irregular inconsistent	flee–fled	1	6	3	2	.52	.51	.33
	weave–wove	1	2	0	85	.91	.69	.33
	light–lit	1	3	0	7	.82	.79	.17
	blow–blew	4	10	149	26	.99	.99	.67
	freeze–froze	1	2	1	2	1.0	.94	.83
	spit–spat	2	4	47	12	.97	.91	.50
	cast–cast	1	3	4	5	.88	.79	.67
	slay–slew	1	10	0	631	.67	.40	.00
	fly–flew	1	7	6	47	.99	.96	.60