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Spelling via semantics and phonology: exploring the effects of age, Alzheimer's disease, and primary semantic impairment

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Abstract

Spelling performance across a common set of stimuli was examined in young adults, healthy older adults, individuals with early stage dementia of the Alzheimer's type (DAT), and four individuals with a primary semantic impairment (PSI). The stimuli included homophones and low-frequency sound-to-spelling consistent (i.e. words with more predictable spellings) and inconsistent words (i.e. words with less predictable spellings). The results indicate that when spelling homophonic words (spelling/pleɪn/ as *plane* versus *plain*), younger adults and to a greater extent individuals with PSI placed relatively more emphasis on phonological information (i.e. spell the word based on sound-to-spelling principles) whereas healthy older adults and individuals with DAT placed relatively more emphasis on semantic information (i.e. spell the word based on the dominant usage). For non-homophonic words, large consistency effects (spelling *plaid* as *plad*) were observed for both individuals with DAT and individuals with PSI. It is proposed that the decrease in accuracy for inconsistent words has different bases in DAT and PSI. We propose that deficits in attentional control (i.e. selection) underlie performance in DAT whereas disruption of semantic representations underlies performance in PSI.

Keywords: Semantic dementia; Homophone spelling; Attentional selection

1. Introduction

Research on lexical processing has benefited considerably from investigations of individuals who have distinct behavioral profiles. For example, the contrast between phonological and surface dyslexia have been taken as critical support for dual-route models of visual word recognition (see [9]). Most of this initial work has involved investigations of processes involved in route to word recognition, as reflected by naming and lexical decision performance. More recently, researchers have become interested in addressing processes across different neuropsychological populations that are involved in outputting orthographic patterns from recognized words, i.e. spelling performance (e.g. [13–15,24]).

The work on spelling appears to converge with the work on word recognition. In two recent studies by Glosser and coworkers [13,14], spelling performance of individuals with DAT and healthy controls was compared across three different types of high- and low-frequency words: (1) consistent sound-to-spelling words containing sounds that are strongly associated with one spelling (e.g. /æʃ/ as in *flash*); (2) inconsistent sound-to-spelling words with at least one sound that is associated with two spellings (e.g. /it/ as in *heat* and *beet*); and (3) inconsistent sound-to-spelling words that contain sounds that are strongly associated with a different spelling pattern (e.g. the /æd/ sound in *plaid* is most typically spelled as *ad* as in *dad*, *pad*, and *sad*). Individuals with DAT performed worse than controls across all word types and more so for low-frequency inconsistent sound-to-spelling words (e.g. *plaid*). Glosser et al. also examined reading aloud, and individuals with DAT exhibited an increase in errors for inconsistent words in both tasks. This finding is consistent with studies of reading aloud that demonstrate that individuals with DAT exhibit an increase in errors for inconsistent words (e.g. [4,29,40]).

Glosser et al. attributed the differences in spelling performance between individuals with DAT and healthy controls to deficits in semantic and attentional processes rather than language-specific processes. In this paper, we suggest that

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the influence of semantics remains relatively intact at least in early stage DAT, and that a breakdown in attentional control (i.e. selection) contributes to the deficits in the spelling and reading of inconsistent words. Specifically, individuals with DAT have difficulty selecting response appropriate information and inhibiting response inappropriate information (see [3], for a review). For example, when presented with the word /plæd/, individuals with DAT will have difficulty selecting the appropriate spelling *plaid* and/or inhibiting incorrect spellings such as *plad*.

In order to better understand the role of semantic information in spelling performance, Graham et al. [15] recently studied individuals with semantic dementia (SD). They found that individuals with SD produced an exaggerated consistency effect (i.e. more errors for inconsistent words than for consistent words) compared to healthy older adults. SD is a progressive dementia that disproportionately affects semantic memory (i.e. knowledge about the relationships among concepts, general world knowledge, and knowledge of objects and their functions) and is associated with neural degeneration of the anterior temporal neocortex [17,35]. Furthermore, SD appears to be behaviorally and pathologically distinct from Alzheimer's disease and frontal lobe dementia [18]. The exaggerated consistency effects in the spelling performance of individuals with SD observed by Graham et al. is consistent with studies of reading aloud where consistent and inconsistent words are compared in this population [28].

Graham et al. interpreted their results within the general framework of parallel-distributed-processing (PDP) models [32,33]. In these models, knowledge of the spelling-to-sound and sound-to-spelling relationships of words is distributed among connection weights in a network of simple processing units that exist on three interconnected levels: (a) phonology, (b) semantics, and (c) orthography. When spelling verbally presented words, there are two possible ways in which propagation can spread in the network: (a) from phonology to orthography, and (b) from phonology to semantics to orthography. Spelling (and reading) inconsistent words is more difficult than consistent words because the connections in the network between phonology and orthography are weaker for inconsistent words due to the relatively rare associations established during learning between the particular sounds and spellings found in these words. For example, the /æd/ sound existing in *plaid* is associated with four different spellings (e.g. *aid*, *ad*, *add*, and *ade*), whereas the /ʌntʃ/ sound in *munch* is associated with only one spelling that exists in a large number of words (e.g. *munch*, *lunch*, *bunch*, *crunch*, etc.). Because the connections between orthography and phonology are weaker for inconsistent words, researchers have argued that the semantic system provides an additional source of information for these words (see [11,41] for evidence with healthy individuals). When this system is damaged (e.g. in SD), the performance of inconsistent sound-to-spelling words suffers disproportionately.

Like SD, the exaggerated consistency effect in DAT could also be due to a damaged semantic system in the PDP model. However, as previously mentioned, another possibility is that the attentional control mechanism that is used to select the correct response and/or inhibit incorrect responses among various activated spellings is deficient in DAT. Because their phonological patterns are associated with a variety of spellings, inconsistent words would be more likely to activate multiple responses than consistent words. Thus, if the attentional control mechanism were deficient, the spelling of inconsistent words would suffer disproportionately.

The results from previous work on spelling can also be interpreted in terms of the dual-route model of word processing [8,9,21,30,31]. Although many exemplars of the dual-route model have been used almost exclusively to explain visual word recognition, they can be easily applied to spelling, and we draw from them to explain spelling performance. In the dual-route model, lexical and sublexical routes are used to compute a word's spelling. In the lexical route, semantic, phonological, and orthographic representations exist for each word in the speller's vocabulary. These representations are interconnected and interactive. When a word is spoken, a phonological representation becomes activated. The activation of the phonological representation can be used to access the word's orthographic representation directly (phonology to orthography) or indirectly (phonology to semantics to orthography). Thus, there are actually two routes that can be used to spell words within the lexical route. In the sublexical route, a phonological representation can be converted into an orthographic representation via a set of phoneme-to-grapheme correspondence (PGC) rules. These rules may be categorical (i.e. always mapping a particular phoneme to a particular grapheme) and correspond to the most frequent mappings between phonemes and graphemes (see [8,9] for this approach applied to reading) or they may be probabilistic (see [21]), mapping phonemes onto graphemes as a function of the relative frequency of a particular mapping across words in a given language. For example, although /ʃ/ can be spelled either with *sh* or *ch*, the most common spelling is *sh* so /ʃ/ would most likely be spelled *sh* by the sublexical route. In the model, inconsistent words usually would require lexical access for correct spelling whereas consistent words can be spelled correctly via either route. For example, the inconsistent word /ʃef/ would most likely be spelled *shef* by the sublexical route due to the misapplication of PGC rules whereas the consistent word /ʃelf/ would be spelled *shelf* by either route. According to the dual-route model, increased consistency effects in SD would be due to damage to the lexical route where the semantic system is located. This would produce a disproportionate reliance on the sublexical route compared to healthy individuals. Interestingly, there are two possible explanations for increased consistency effects in DAT. First, an increased consistency effect could be due to damage to the lexical route similarly to that found in SD. Second, the effect could be due to a deficient attentional control mechanism needed to select the correct spelling generated by the lexical route from the incorrect spelling generated by the sublexical route (see [4] for a similar idea used to explain reading aloud performance in DAT).

In the current study, we examined spelling performance of homophones and words that vary in their sound-to-spelling consistency in healthy young adults, healthy older adults, individuals with early stage DAT, and individuals with a primary semantic impairment (PSI). Although it is quite possible that three of the individuals referred to as PSI have SD distinct from DAT, we are reluctant to make such a categorization without neuropathological confirmation (see [26]). As described in Section 2, the identification of individuals with PSI was based initially on an existing set of psychometric tests that have been used to longitudinally track a large cohort of healthy older individuals and individuals with DAT. The individuals with PSI produced exaggerated breakdowns in semantic tasks, but normal performance in non-semantic tasks. These individuals were quite discontinuous in their performance compared to the remaining cohort of subjects. Moreover, additional testing on standard tasks used to identify individuals with semantic dementia confirmed our expectations. Finally, as discussed below, structural MRI provided converging evidence that these individuals with PSI had distinct patterns of asymmetric (left greater than right) atrophy.

1.1. Homophone spelling

The present study took a novel approach to investigating the role of sound-to-spelling consistency in spelling performance across these groups of individuals. In particular, we explored spelling performance on two different types of homophones. In the first type of homophone, the spelling of the dominant interpretation of this form is consistent with the most common spelling of the rime. Hence, both meaning and sound-to-spelling correspondence worked in the same direction. For example when auditorily presented with /weɪst/, and asked to generate an associate, subjects generate associates to the meaning of *waste* more often than to *waist*. In addition, the /eɪst/ phonology is more strongly associated with the *aste* spelling (occurring in four words) than the *aist* spelling (occurring only in *waist*, see [44]). In the second type of homophone, the dominant meaning of the homophone included an inconsistent sound-to-spelling mapping. Hence, for these items, the meaning drove one interpretation, but the spelling drove another interpretation. For example, according to the Galbraith and Taschman [12] norms, *plane* is the dominant meaning for /pleɪn/, but the /eɪn/ sound is more commonly spelled as in *plain* (16 spellings for *ain*, and 7 spellings for *ane* [44]).

In the present study, group differences in the use of meaning were assessed by comparing the patterns of performance on these two types of homophones. Each type of homophone was similar in terms of meaning dominance. Therefore, if participants rely more on meaning, they should spell the dominant meaning interpretation independent of the dominance of the spelling pattern (i.e. *waste* and *plane*). However, if participants rely more on spelling patterns instead of meaning, when the dominant meaning coincides with a subordinate spelling pattern, then subjects might generate the word with the dominant spelling pattern (i.e. *plain* rather than *plane*).

It is important to note that both the PDP model and the dual-route model can accommodate spelling homophones via meaning and/or phonology. In the PDP model, if the propagation of activation from phonology to semantics to orthography is stronger than that from phonology to orthography, then participants will spell the homophone that is dominant by meaning regardless of spelling dominance. However, if the propagation from phonology to orthography is stronger than that from phonology to semantics to orthography, then participants will spell the homophone that is dominant by spelling regardless of meaning dominance. In the dual-route model, if the lexical route prevails, and the semantic system is accessed, then participants will spell the homophone that is dominant by meaning regardless of spelling dominance. Conversely, if the sublexical route prevails, then participants will spell the homophone that is dominant by spelling regardless of meaning dominance. Thus, the homophone manipulation does not distinguish between models. Rather, the purpose is to determine empirically the degree to which distinct populations rely on semantic versus phonological information when spelling words.

Turning now to the predictions regarding age effects, older adults might be more apt to use meaning than younger adults. There has been some recent evidence suggesting that older adults rely more on lexical/semantic information whereas younger adults rely more on sublexical information in visual word recognition [2,39]. Therefore, relative to younger adults, older adults might be more likely to spell the homophone that corresponds to the dominant meaning, even when this homophone corresponds to a subordinate spelling pattern. Regarding the performance of individuals with DAT, a similar pattern to that of healthy older adults might be expected if the semantic representation is automatically activated when the word is auditorily presented. When attentional demands are minimized, patients with DAT show normal levels of semantic priming [1,27]. In terms of homophone spelling, attentional demands are minimized because the different possible spellings that are associated with a phonological pattern are equally correct. In other words, there is not a response that needs to be selected for and/or another that needs to be selected against. Thus, if patients with DAT have deficient attentional processes, their spelling of homophones should not differ from that observed in healthy adults. In contrast, individuals with PSI, who presumably have a deteriorated semantic representational system, should rely more heavily on sound-to-spelling connections and they should spell the homophone that corresponds to the dominant spelling pattern regardless of its meaning dominance. Of course, if the individuals with DAT have a primary breakdown in semantic memory, then one might expect a similar pattern of homophone spelling as that found in the individuals with PSI.

1.2. Sound-to-spelling consistency effects

Spelling performance on low-frequency consistent words was compared to low-frequency inconsistent words. It is important to note here that consistency reflects sound-to-spelling consistency as opposed to spelling-to-sound consistency. Specifically, consistent words contain phonological rimes that are associated with the spelling found in those words (e.g. *prong*), and inconsistent words contain phonological rimes that are associated with an alternative spelling (e.g. *plume* wherein the rime can also be spelled *oom* as in *doom* or *omb* as in *tomb*).

Based on the studies previously discussed, we predict that larger sound-to-spelling consistency effects will be observed in patients with DAT and in patients with PSI than in healthy older adults. This effect should be largest in the individuals with PSI.

Finally, it is important to note that in order to minimize working memory and attentional demands, we used short words as stimuli. Spelling is a multi-component task wherein the speller must maintain in working memory the to-be-spelled word, the letters that have been reported, and the letters that have yet to be reported. Of course, memory and attentional demands cannot be entirely eliminated, but the use of short words minimizes such demands. The length of our words (mean length = 4.5) was nearly half of the length of MacKay and Abrams' [24] stimuli (mean length = 8.9), slightly shorter than Glosser et al. [13] and Glosser et al.'s [14] stimuli (mean length = 5.2), and comparable to Graham et al.'s [15] stimuli (experiment 1: mean length = 4.5, experiment 2: mean length = 4.3).

2. Method

2.1. Participants

One hundred eighty-eight individuals participated in the study. This sample included 43 young adults (mean age 19.6 years, range 18–28 years), 81 older adults (mean age 78.6 years, range 58–96 years, mean education 15.4 years), 61 individuals with either very mild DAT or mild DAT (mean age of 77.5 years, range 60–93 years, mean education 14.3 years), and four individuals with PSI. The four participants with PSI are individually referred to as PSI1 (age = 62, education = 12 years), PSI2 (age = 73, education = 16 years), PSI3 (age = 84, education = 14 years), and PSI4 (age = 69, education = 12 years) and were identified exclusively based on psychometric test performance as described in detail below.

The young adults were students at Washington University who were either paid six dollars or received course credit for their participation. The remaining participants were recruited from the Memory and Aging Project (MAP) participant pool at the Alzheimer's Disease Research Center (ADRC) at Washington University. These participants were screened for depression, severe hypertension, possible reversible dementias, and other disorders that could affect cognitive performance. Individuals with DAT were included or excluded based on the criteria determined by the National Institute of Neurological and Communicative Disorders and Stroke and Alzheimer's Disease and Related Disorders Association [25]. Dementia severity was assessed via the Washington University Clinical Dementia Rating (CDR) scale. The CDR scale is reliable and the accuracy of the diagnosis by the research team has been well documented (e.g. [6]). Using this system, healthy control individuals were classified as having a CDR of 0.0. The participants with dementia were classified as having either very mild dementia (CDR 0.5) or mild dementia (CDR 1.0).

The classification of PSI was made via a selection of psychometric test scores provided by the ADRC (see Tables 1 and 2). Three individuals were selected from a sample of

Table 1
Raw psychometric scores for each of the participants with PSI

	PSI1	PSI2	PSI3	PSI4
Semantic measures				
Animal fluency (15 s)	1	3	1	4
Boston naming	5	12	16	8
AMNART	10	10	8	7
Pyramids and palm trees[a]	0.52	0.67	0.73	0.69
Word/picture matching[a]	0.20	0.66	0.78	0.78
Synonym judgment[a]	0.54	0.52	0.60	0.52
Non-semantic measures				
Benton copy	9	9	10	10
Digit span—forward	7	6	6	7
Digit span—backward	4	3	4	6
WAIS block design	20	20	24	44
WAIS digit symbol	41	41	28	41

[a] Proportion correct.

Table 2
The *z*-transformation of psychometric scores for the participants with PSI

	PSI1	PSI2	PSI3	PSI4
Semantic measures				
Animal fluency (15 s)	−1.97	−1.18	−1.97	−0.79
Boston naming	−3.37	−2.83	−2.52	−3.08
AMNART	−1.97	−1.97	−2.17	−2.26
Mean	−2.44	−1.99	−2.22	−2.04
Non-semantic measures				
Benton copy	−0.03	−0.03	0.52	0.52
Digit span—forward	0.80	−0.02	−0.02	0.80
Digit span—backward	−0.16	−0.89	−0.16	1.30
WAIS block design	−0.37	−0.37	−0.01	1.74
WAIS digit symbol	0.27	0.27	−0.53	0.27
Mean	0.10	−0.21	−0.04	0.93

Note: The data from the pyramids and palm trees task, the word/picture matching task, and the synonym judgment task (see Table 1) has been collected on a relatively small number of subjects. For this reason, *z*-transformations were not performed on this data.

315 individuals who participated in MAP during 1999. The fourth individual was identified later, also via psychometric test scores, when first enrolled in the MAP participant pool in 2001. Raw scores (Table 1) from two categories of tests, semantic and non-semantic, were converted into *z*-scores (Table 2) for all of the individuals in the sample. The tests classified as semantic included animal fluency, Boston naming, and The American Version of the National Adult Reading Test (AMNART). Individuals with SD perform well below average on tests such as these (e.g. [17]). The non-semantic tests included Benton copy, digit span—forward, digit span—backward, WAIS block design, and WAIS digit span. Once scores on these tests were converted into *z*-scores, separate composite *z*-scores were compiled for semantic and non-semantic tests. For the four individuals with PSI, the semantic *z*-scores were −2.44, −1.99, −2.22, and −2.04 and their non-semantic *z*-scores were 0.10, −0.21, −0.04, and 0.93, respectively (see Table 2). The relation between these subjects identified as having PSI, based on psychometric test scores, and SD as formally described by Hodges et al. [17], is that of overlap. As noted below, some but not all of our patients with PSI will likely meet the criteria for SD. Moreover, it is worth noting that that independent clinical assessments of these four individuals indicated that PSI1 had DAT with progressive aphasia, PSI2 had incipient dementia predicted to progress along with progressive aphasia and frontal lobe dysfunction, PSI3 had DAT (qualified by MRI, see below), and PSI4 had possible frontal lobe dementia and/or semantic dementia. All four individuals received a CDR score of 0.5, very mild dementia.

Fig. 1 displays the relationship between the semantic and non-semantic *z*-scores across all individuals. As shown here, there is a strong relationship between performance on the semantic and non-semantic measures ($r = 0.52$), and the four individuals with PSI were quite discontinuous with the remaining subjects.

To address the issue of whether the individuals with PSI have a true semantic impairment as opposed to simply a difficulty on naming tests, we were able to utilize data we had previously gathered on these people as part of an ongoing research study investigating semantic deficits. All four individuals completed several subtests from the Hodges semantic battery [16], including the picture version of the pyramids and palm trees test [19], a word to picture matching task, and a synonym judgment task [43]. In the pyramids and palm trees task, the subject was instructed to select from two pictures that which was more similar to a target picture (e.g. a pine tree or a palm tree compared to a pyramid). The word-picture matching task consisted of 64 pictures taken from the Snodgrass and Vanderwart [34] norms. In this task, a spoken word was given to the subject and (s)he was asked to select from eight choices, the picture that matched it. In the synonym judgment task, the subject was instructed to select a word that was synonymous with a target word from two alternatives.

In addition to collecting semantic data on the four individuals with PSI, we also have recently begun collecting data on healthy controls and individuals with very mild DAT. For the pyramids and palm trees test, the mean correct for PSI, DAT, and controls, respectively, was 0.65, 0.96, and 0.95. For word-picture matching, the respective means were 0.61, 0.98, and 0.99. For synonym judgment, the means were 0.55, 0.82, and 0.84. Obviously, the individuals with PSI are performing very poorly on these semantic tests compared to the

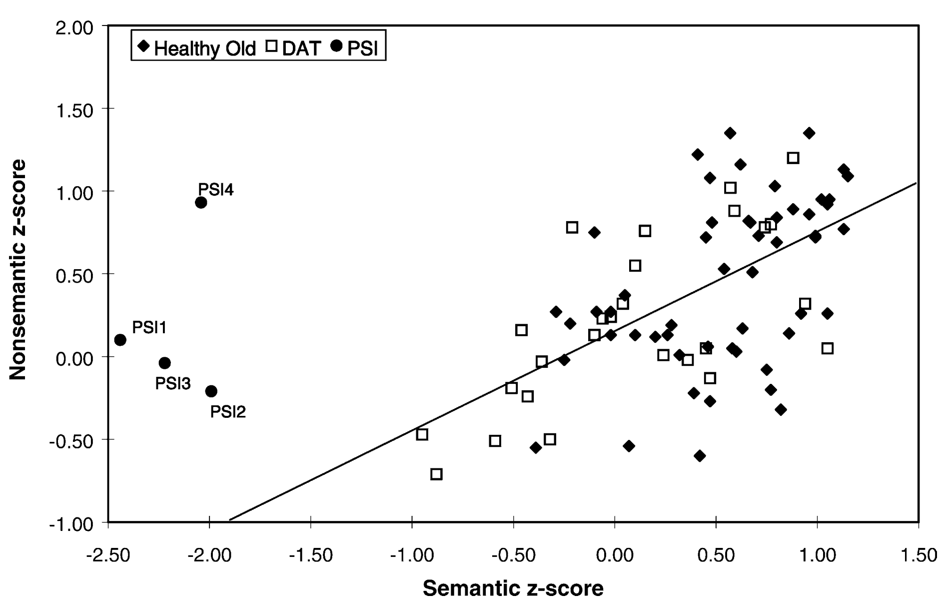

Fig. 1. Scatter plot of semantic and non-semantic *z*-scores for 83 individuals who participated in the current study. Each point represents a single individual with diamonds representing non-demented control participants (CDR 0.0), squares representing very mild (CDR 0.5) and mildly demented participants (CDR 0.5), and circles representing the four individuals with PSI. The line represents the best-fit to the data excluding the four PSI participants and $r = 0.58$.

Table 3
Mean psychometric scores (standard deviations in parentheses) for healthy older adults, individuals with DAT, and individuals with PSI

Test measure	Group					
	Healthy old ($n = 81$)	DAT ($n = 61$)	PSI			
			PSI1	PSI2	PSI3	PSI4
Word fluency	31.8 (11.0)	20.7 (9.2)	13	12	7	4
Boston naming	55.0 (5.5)	43.7 (13.0)	5	12	16	8
WAIS information	21.8 (4.1)	14.9 (6.4)	1	6	6	7
Logical memory	9.6 (3.1)	4.8 (3.8)	1	2	3	2
Associate memory	14.9 (3.6)	9.8 (4.2)	N.S.	5	5	3
Benton copy	9.7 (0.7)	9.1 (1.2)	9	9	10	10
Trailmaking A[a]	36.8 (10.8)	63.2 (34.0)	58	50	54	37
Block design	31.0 (8.5)	22.7 (10.1)	20	20	24	44
Mental control	7.5 (1.6)	6.1 (2.3)	9	6	5	8
Digit symbol	46.1 (9.4)	32.3 (14.3)	18	41	28	41
Digit span	11.4 (2.1)	10.1 (2.0)	11	9	10	13

N.S. indicates that no score was obtained for this measure.
[a] Represents time in seconds.

healthy controls and individuals with DAT. In order to test the reliability of these differences, we entered group (control, $N = 3$, DAT, $N = 7$, PSI, $N = 4$) as a factor on separate one-way ANOVAs on each measure. Even though these were relatively small N's, the main effect of group was significant in each analysis (all $P < 0.01$). Pairwise comparisons revealed that control and DAT groups did not differ on any of the semantic measures, whereas individuals with PSI performed lower than both DAT and control groups on Pyramids ($P < 0.01$), word-picture matching ($P < 0.07$), and synonyms ($P < 0.01$). We should note that because this data has been collected on a relatively small number of participants so z-transformations were not performed on this data and do not appear in Table 3. Overall, these findings are consistent with the argument that the individuals with PSI have a true semantic deficit and not simply a naming difficulty.

The means and standard deviations from the remaining psychometric measures from the healthy older adults, individuals with DAT, and the four individuals with PSI are presented in Table 3. The young adults were not tested on the psychometric battery. A series of t-tests indicated that performance decreased for individuals with DAT, compared to the healthy older adults on all measures (all $P < 0.0001$). It should also be noted that the four individuals with PSI scored relatively higher on the word fluency measures than the animal fluency measures, a pattern that is also consistent with previous reports of SD (e.g. [15]).

Based on the performance of some of the “non-semantic” tests in the psychometric battery (e.g. WAIS information, memory tests and block design), it is possible that one might argue that some of our PSI sample might have a more general impairment. However, we do not think that disrupted performance on these tasks is indicative of a more general impairment. Rather, it is more likely that individuals with PSI have difficulty on the WAIS information and memory tests because they are also dependent on linguistic information. Of course, memory is also involved in these tasks so it becomes difficult to tease apart the causal influence. However, on the Digit Span tasks, the PSI individuals were well within the normal range of performance. Finally, we do not think that the performance by two of our PSI individuals on one of the tasks, i.e. the block design task, warrants a change in classification because this task may reflect a difficulty in dealing with relatively complex instructions rather than a general impairment.

2.2. Structural magnetic resonance imaging

In addition to psychometric performance, multiple structural MRI images were obtained on each of the individuals with PSI, along with a subset of the remaining subjects ($N = 23$; 15 control and 8 DAT). Images were acquired using a T1-weighted MPRAGE sequence (TE = 4 ms, TR = 9.7 ms, 1 mm × 1 mm × 1.25 mm resolution; flip angle = 10°) and characterized qualitatively as well as quantitatively. For quantitative atrophy assessment, an automated procedure was employed for brain segmentation into cerebral spinal fluid (CSF), gray matter, and white matter [37]. For this analysis, each set of anatomic images was averaged, motion-corrected for between-acquisition movement [36], interpolated to fit into a standard atlas space ([42], using 1-mm isotropic voxels), and segmented into tissue classes using the signal intensity histogram. The percentage of tissue classified as CSF was used as the measure of atrophy and computed separately for the whole-brain, left-hemisphere, and right-hemisphere.

Qualitative inspection of the structural images revealed evidence of mixed etiology among the four participants with PSI. Fig. 2 displays a representative structural MRI image for each of the four individuals as well as the same image segmented to estimate CSF. PSI1 and PSI4 demonstrated focal atrophy of the anterior temporal poles, consistent with the SD patients described by Hodges et al. [17]. PSI2 showed marked atrophy including the temporal poles. PSI3 showed

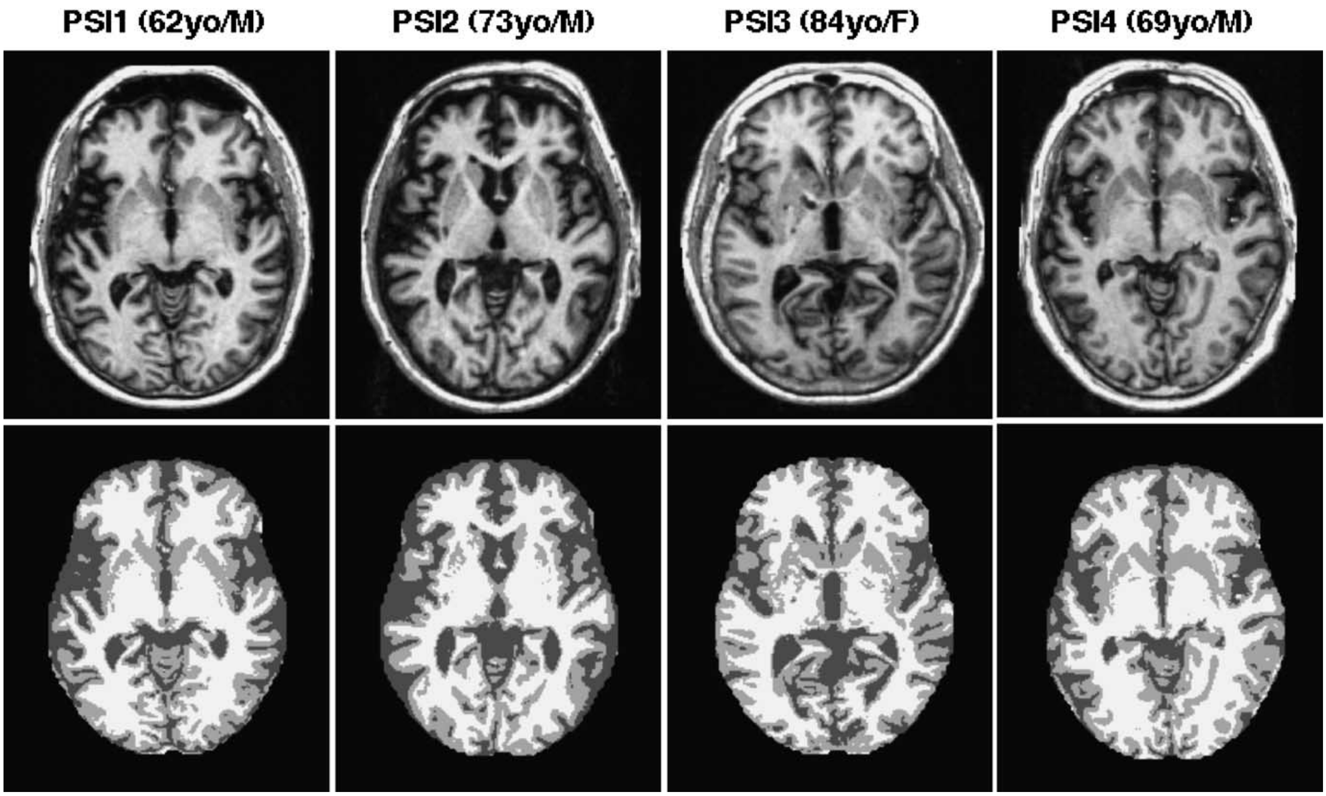

Fig. 2. MRI structural images of the four individuals with PSI. The top row shows a representative axial section from the raw structural image of each participant, averaged in atlas-transformed space. The images are labeled at the top with the specific PSI participant including age in years-old (yo) and gender. The bottom row shows the segmented images with the darkest gray representing cerebral spinal fluid (CSF), medium gray representing gray matter, and white representing white matter.

minimal atrophy but presented with multiple lacunar infarcts, including a prominent infarct of the left thalamus.

Fig. 3 displays the results from automated atrophy assessment, which confirmed and extended the observations made by qualitative inspection of the images. Fig. 3 displays the relative CSF in the left versus the right-hemisphere. All four individuals with PSI have an asymmetric pattern of CSF, suggesting greater tissue loss in the left-hemisphere than the right, compared to the remaining individuals. In fact, ranking the four individuals with PSI among the 23 controls and DAT participants indicated PSI1, PSI3, and PSI4 were clear outliers in terms of asymmetry and PSI2 fell within the top six. Also of interest was the finding that the four participants with PSI differed markedly among themselves in terms of overall atrophy with PSI3 showing minimal whole-brain atrophy and PSI2 showing an extremely high level of atrophy, consistent with the qualitative impression of mixed etiology. Thus, although these individuals have similar behavioral profiles as measured by psychometric testing, the etiology is likely different across the individuals.

2.3. Stimuli

The stimuli are presented in the Appendix. Eighteen of the 20 homophones were selected from the Galbraith and Taschman [12] norms, and 2 homophones were added (*manner* and *current*) so that 10 homophones occurred in each condition. Of the 20 homophone pairs selected, 10 included members that were defined as dominant in terms of both meaning and spelling, and 10 included members that were dominant by meaning and subordinate by spelling. Meaning dominance was determined according to the Galbraith and Taschman [12] word association norms. A member was considered dominant if the words that were generated were more often associates to it than the other member of the pair. Spelling dominance was determined according to the Ziegler et al. [44] norms. A homophone member was considered spelling dominant if its phonological units were more commonly spelled like it than like the other member of the pair.

In addition to the homophones, low-frequency consistent and inconsistent words were included.[1] The low-frequency

[1] The words in the consistent and inconsistent conditions each were composed of two different types of words. The consistent word condition was made up of words containing phonological rimes (i.e. the vowel and subsequent consonants) associated with many (e.g. *mound*) or few (e.g. *gulp*) neighbors. The inconsistent word condition was comprised of words that were either spelling-to-sound consistent (e.g. *plume*) or inconsistent (e.g. *plaid*). Separate analyses indicated that the effects of these factors were relatively small compared to the overall effect sound-to-spelling consistency, and thus were omitted. Collapsing across these conditions does not qualify the pattern of results reported in this paper.

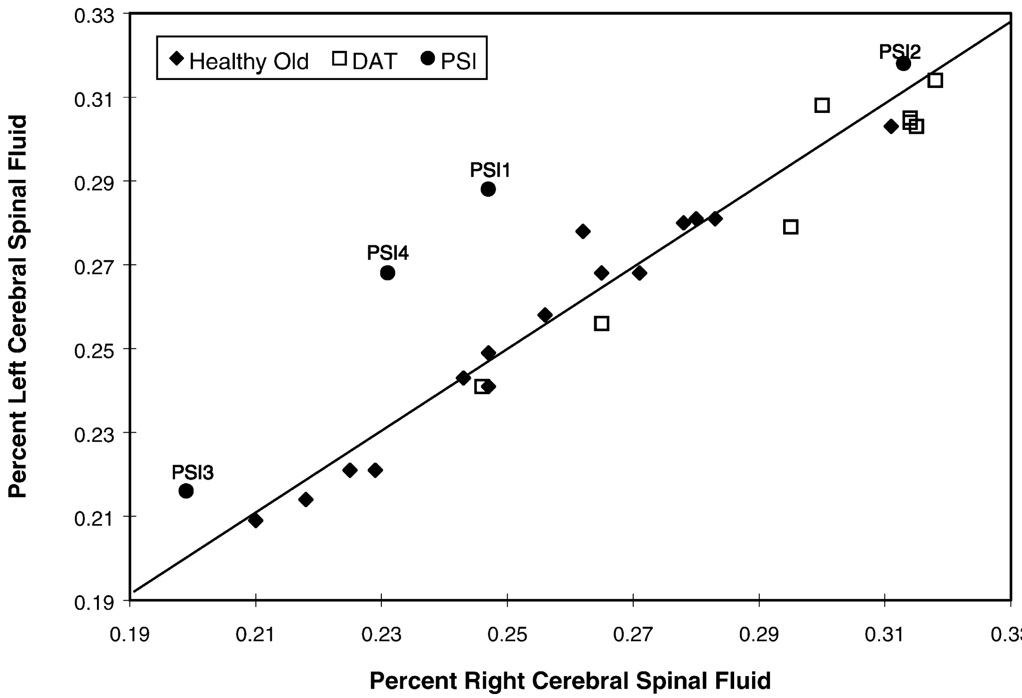

Fig. 3. Scatter plot of right and left-hemisphere atrophy for 27 individuals who participated in the current study. Atrophy is measured as the percentage of tissue classified as cerebral spinal fluid (CSF) in each of the hemispheres. Each point represents a single individual with diamonds representing non-demented control participants (CDR 0.0), squares representing very mildly and mildly demented participants (CDR 0.5 and CDR 1.0), and circles representing the four individuals with PSI. The line represents perfect symmetry where CSF is equal between the left and right-hemispheres.

consistent and inconsistent words were equated on length and frequency [22]. Friend and enemy estimates were based on the rime unit and were determined via the Ziegler et al. [44] norms (see Table 4 for stimulus characteristics).[2]

2.4. Procedure

The 80 words were auditorily presented in the same random order for all subjects. Participants were tested individually and they were instructed to spell each word verbally. An oral spelling task was used to simplify the output (i.e. having participants write their responses could produce additional error in coding). They were informed that some of the words could be spelled in more than one way and if they noticed this, then they should spell the first word that came to mind. Words were presented one at a time to each participant and the participant repeated each word back to the experimenter. If the participant repeated a different word, the process was repeated until the participant repeated the target word correctly. The experimenter manually recorded each participant's response.

Table 4
Stimulus characteristics for the words used in the study

	Frequency[a]	Length	Friends	Enemies
Homophone—dominant spelling[b]	53.2	4.4	10.5	9.9
Homophone—subordinate spelling[c]	50.3	4.6	4.8	16.8
Homophone—dominant spelling[c]	56.8	4.4	15.1	7.4
Homophone—subordinate spelling[b]	55.7	4.6	3.1	17.9
Consistent	47.5	4.4	5.6	0.0
Inconsistent	47.3	4.5	0.4	12.5

Note: Values reflect mean.
[a] Transformed using the formula $40 + 10 \log(f + 1)$ (see [2]).
[b] Dominant by meaning.
[c] Subordinate by meaning.

3. Results and discussion

Separate analyses were conducted on the proportion correct spelling of each class of stimuli to address distinct

[2] Friends and enemies refer to the overall consistency of the homophone member that was dominant by meaning. This does not necessarily represent the sound-to-spelling relationships these members have with the subordinate (by meaning) member. For example, 16 words containing the sound /eɪt/ are spelled as in *ate*, and only 3 words are spelled as in *eight*, but *ate* has 11 enemies due to the spellings *ait*, *aight*, *ete*, and *eat*. Also, the friend and enemy counts do not include the values for *manner* and *current* (meaning dominant—spelling dominant condition) and *capitol* and *naval* (meaning dominant—spelling subordinate condition) because the Ziegler et al. [44] norms only include estimates for monosyllabic words. A friend and enemy count was not included for *wrap* (meaning dominant—spelling subordinate condition) because in *wrap*, the *wr* onset is the inconsistent unit, and the Ziegler et al. norms only include values for rime units.

influences of semantic and phonological information. Each initial analysis included young adults, healthy older adults, and individuals with DAT as levels of the grouping variable. Subsequent analyses were conducted with age (young versus old) and DAT (old versus DAT) as the grouping variables whenever the initial analyses with all three groups were significant in either a main effect or interaction. For the DAT analyses, the variance associated with education was removed through an analysis of covariance because education differed significantly between the healthy old participants and those with DAT, $t(140) = 2.03$, $P < 0.05$, and also because education is likely to influence spelling performance. Similar procedures were not used for the Age analyses because education was unavailable for the young adult participants. Significance level was set at $P < 0.05$, unless otherwise noted. Inferential statistics were not conducted on the data from the individuals with PSI due to the low number of participants in this group ($N = 4$). However, as shown below, the data for the four individuals with PSI are remarkably consistent at the individual level. Full descriptions of the psychometrics and MRI profiles of the individuals with PSI are presented in Section 2.

3.1. Homophone spelling

Fig. 4 presents the group means for overall accuracy for each condition collapsed across homophone type. For example, both *waste* and *waist* were counted as correct spellings for the dominant meaning-dominant spelling condition, and both *plane* and *plain* were counted as correct spellings for the for the dominant meaning and subordinate spelling condition. Figs. 5 and 6 display the probability of producing the correct spelling for each homophone type, i.e. corrected for accuracy. Fig. 5 corresponds to the dominant meaning-dominant spelling condition (e.g. *waste* versus *waist*), and Fig. 6 corresponds to the dominant meaning-subordinate spelling condition (e.g. *plane*versus *plain*). Separate group (young, old, DAT) by homophone type (dominant meaning-dominant spelling, dominant meaning-subordinate spelling) ANOVAs were conducted for: (a) the overall performance, and (b) the adjusted scores (i.e. the probability of generating the correct spelling of the homophone with the dominant meaning given a correct spelling). The first analysis comparing the three groups on overall performance yielded a significant effect of group, $F(2, 182) = 9.31$, $\text{MSE} = 0.12$, which indicated that individuals with DAT were marginally less accurate spellers than older adults, $F(1, 139) = 3.55$, $\text{MSE} = 0.02$, $P = 0.06$, and older adults were less accurate spellers than younger adults, $F(1, 122) = 10.01$, $\text{MSE} = 0.06$. No other effects were significant (both $P > 0.19$).

The second set of analyses indicated that the homophones which were dominant in terms of both meaning and spelling were spelled more often than homophones which were dominant in terms of meaning and subordinate in terms of spelling, $F(1, 182) = 219.72$, $\text{MSE} = 5.12$. More importantly, the group by homophone type interaction was highly significant, $F(2, 182) = 10.54$, $\text{MSE} = 0.25$. This interaction was significant in the analysis by age, $F(1, 122) = 19.3$, $\text{MSE} = 0.48$, but not in the DAT analysis, $F(1, 139) = 1.22$, $P > 0.27$. This interaction indicated that young adults were relatively more likely to spell homophones with the dominant meaning and dominant spelling compared to the older adults, $t(122) = 2.38$, and they spelled homophones with the dominant meaning and subordinate spelling less often than older adults, $t(122) = 3.70$. Thus, the homophone spelling data indicate that the younger adults rely less on semantic information than both the older adults and the individuals with DAT, which did not differ.

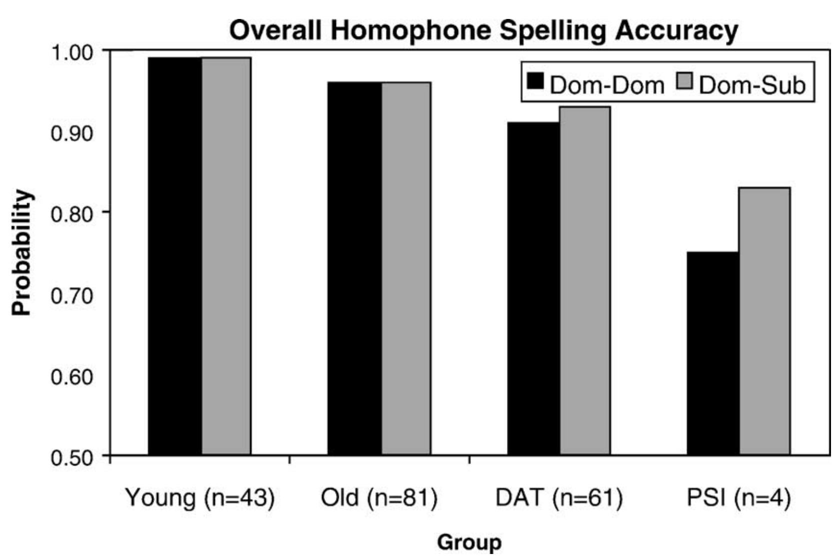

Fig. 4. The probability of producing a correct spelling of either homophone. Dom-Dom refers to homophones with a dominant meaning and a dominant spelling. Dom-Sub refers to homophones with a dominant meaning and a subordinate spelling.

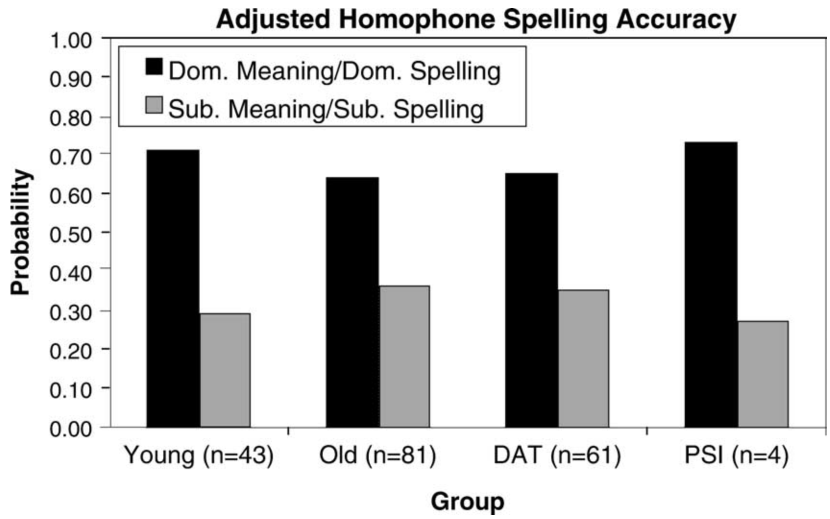

Fig. 5. The probability of producing the spelling of the homophone with the dominant meaning/dominant spelling and the homophone with the subordinate meaning/subordinate spelling given a correct spelling.

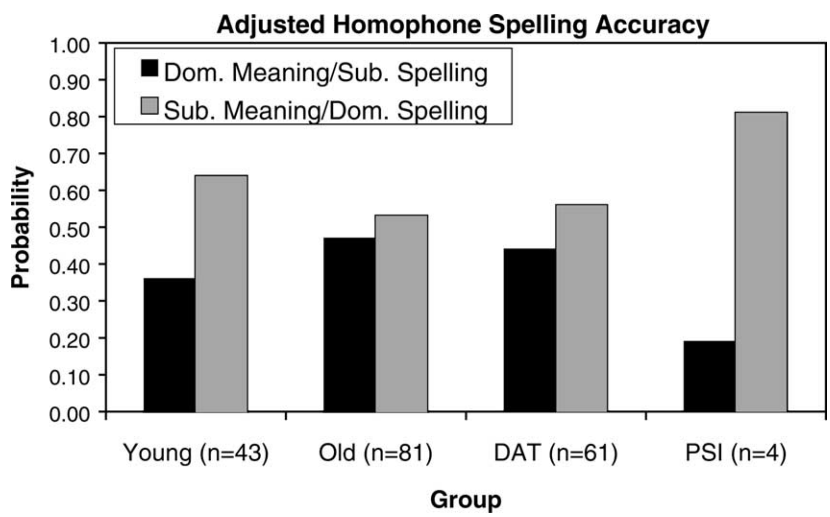

Fig. 6. The probability of producing the spelling of the homophone with the dominant meaning/subordinate spelling and the homophone with the subordinate meaning/dominant spelling given a correct spelling.

As shown in Figs. 5 and 6, the individuals with PSI produced a dramatically exaggerated bias in homophone spelling. Specifically, given a correct spelling, it was quite rare that they spelled a word that was not dominant in terms of spelling. This outcome is consistent with the prediction that the degree to which participants rely on phonological information will be revealed in the pattern of spelling of these two homophone types. Presumably, individuals with PSI cannot rely on meaning during the spelling task and this is reflected clearly in their reliance on dominant spelling patterns. This pattern of spelling is clearly different from that of individuals with DAT who appear to rely on semantic information to the same extent as healthy older adults. Individual homophone spelling data from the participants with PSI are presented in the top two panels of Table 5 and, as shown, are quite consistent at the individual level.

One could argue that the spelling deficits observed in the individuals with PSI are not unique to these individuals but are simply part of a continuum of dementia on which individuals with DAT also fall. If this is the case, then participants with DAT who score low on semantic tests (as do all the individuals with PSI), should also have a similar pattern of spelling performance to the PSI group. To address this issue, we computed a composite score for each participant by summing the Boston naming and animal fluency psychometric test scores.[3] We then used these composite scores to identify within our DAT sample those individuals scoring very low versus those scoring low. After identifying these

[3] Although AMNART scores were used to identify individuals with PSI in 1999, this data was not readily available for all the participants in the current study and therefore was not used in these analyses.

Table 5
Individual PSI spelling data

	PSI1	PSI2	PSI3	PSI4	Mean
Probability of a correct spelling of either homophone					
Dominant meaning-dominant spelling	0.90	0.70	0.60	0.80	0.75
Dominant meaning-subordinate spelling	0.90	0.80	0.90	0.70	0.83
Probability of spelling the homophone with the dominant meaning, given a correct spelling					
Dominant meaning-dominant spelling	0.89	0.57	0.83	0.63	0.73
Dominant meaning-subordinate spelling	0.22	0.13	0.11	0.29	0.19
Probability of a correct spelling for low-frequency words					
Consistent	0.90	0.83	0.47	0.63	0.71
Inconsistent	0.27	0.37	0.37	0.13	0.29

lowest scoring groups, we were then able to further scrutinize spelling performance on these individuals.

There was a large break in performance between one participant's composite score of 26 and another's score of 36 (due to a break in Boston naming scores of 20 and 31 for these two people). We used this breakpoint, which cut off the lowest scoring eleven participants, to define our very low scoring group. There was another natural break in the Boston naming data between scores of 36 and 46 (composite scores of 51 and 52), which was used to separate the low-scoring group from the rest of the sample. This group was comprised of 15 people. It is important to note that all PSI individuals were in the very low group, leaving seven individuals with DAT in that very low group. In fact, the individuals with PSI comprised four of the lowest six composite scores out of the entire sample of 145 subjects. We were then able to compare the spelling performance of the individuals with PSI to that of participants in the very low and low groups for each condition of interest. Regardless of the relatively low Ns in each group, the results were convincing. Results indicated that the PSI group produced more correct spellings of the homophone with the dominant meaning-dominant spelling as compared to both the very low ($P = 0.10$) and low ($P = 0.15$) groups. In addition, the PSI group produced less correct spellings of the homophone with the dominant meaning-subordinate spelling as compared to both the very low ($P = 0.07$) and low ($P = 0.01$) groups. Thus, these results clearly do indicate that the disparate homophone spelling performance of the PSI individuals does not simply reflect the normal variability associated with poor semantic performance by the DAT individuals.

To further address the argument that the individuals with PSI are indeed different from our other participants, we rank ordered participants on the difference between the probability of spelling the homophone with the dominant meaning from the probability of spelling the homophone with the subordinate meaning in the dominant meaning-subordinate spelling condition (e.g. the probability of spelling *plain* instead of *plane*). Those who were more likely to use the dominant meaning (e.g. *plane* i.e. relying more on semantic information) were ranked at the low end, and those who were more likely to use the dominant spelling (e.g. *plain*, i.e. relying more on phonological information) were ranked at the high end. PSI3 was at the 99th percentile, PSI2 was at the 98th percentile, PSI1 was at the 89th, and PSI4 was at the 85th. The other individuals who had a large effect size and who scored at or below the 85th percentile were equally either healthy old or individuals with DAT. It appears that there is real variability in spelling performance regardless of age or dementia, but the fact that all individuals with PSI were at the 85th percentile or higher is indeed striking. In order to better illustrate the difference in effect size for the PSI group compared to the other groups, we plotted this effect size with error bars extending two standard errors from the mean effect size for each group (see Fig. 7). Because of the severe disparity in group size, conventional statistics could not be performed, but the extreme difference in performance between groups is clearly apparent.

3.2. Sound-to-spelling consistency effects

The next set of analyses assessed sound-to-spelling consistency effects. The mean performance of consistent and inconsistent words across groups is displayed in Fig. 8. The results of the ANOVAs indicated that sound-to-spelling consistent words were spelled more accurately than inconsistent words, $F(1, 172) = 294.28$, MSE $= 0.01$, and that spelling ability differed across groups, $F(2, 172) = 15.36$, MSE $= 0.03$. Individuals with DAT were less accurate spellers than healthy older adults, $F(1, 139) = 15.33$, MSE $= 0.03$, but there was no significant difference between younger and healthy older adults, $P = 0.26$. The overall interaction between group and consistency was significant, $F(2, 172) = 17.44$, MSE $= 0.01$. However, this interaction did not approach significance when only age was used as the grouping factor, $F < 1.0$. In contrast, this interaction was significant in the analysis by DAT, $F(1, 139) = 24.74$, MSE $= 0.01$, which indicated that the influence of sound-to-spelling consistency was larger in the individuals with DAT than in the healthy control individuals. Finally, as shown in Fig. 8, the individuals with PSI produced an exaggerated effect of sound-to-spelling consistency compared to the individuals with DAT (see bottom panel of Table 5 for individual data).

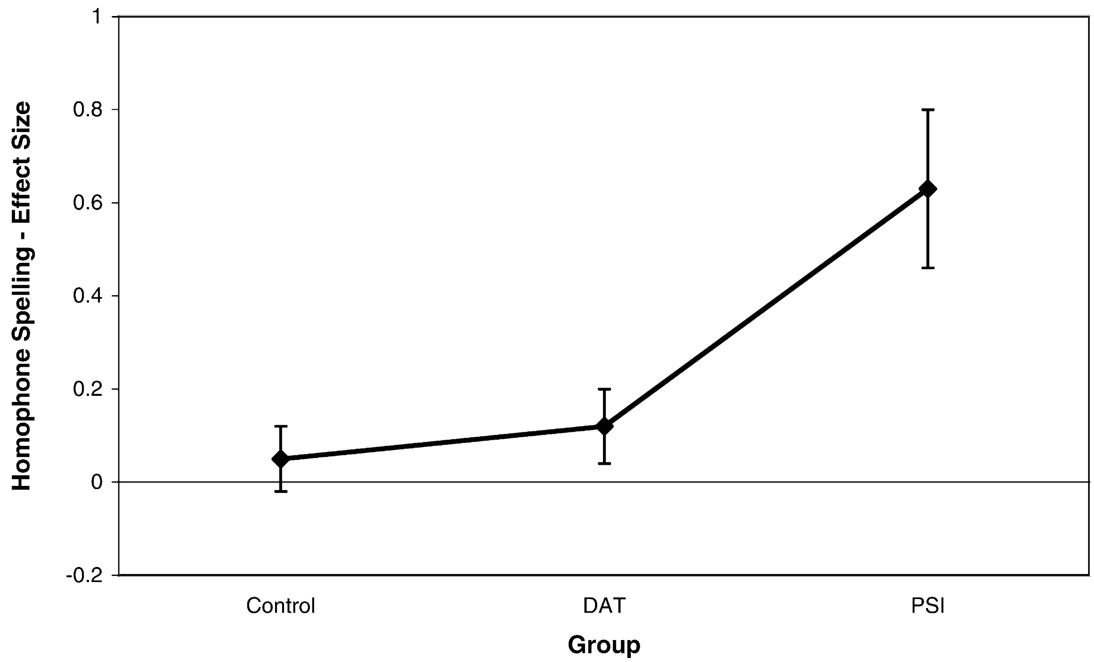

Fig. 7. The homophone-spelling effect size representing the difference in probabilities between spelling the homophone with the dominant meaning and subordinate spelling from the homophone with the subordinate meaning and dominant spelling for healthy older adults, DAT individuals, and PSI individuals.

To illustrate how our PSI patients performed relative to the DAT patients and healthy older participants, we computed the consistency effect (proportion correct for consistent words minus the proportion correct for inconsistent words) for each participant. On this measure, a large score indicates that the individual spelled consistent words much more accurately than inconsistent words. Next, we computed percentile rankings for each of our participants. With one exception (PSI3 = 35th), our PSI patients' rankings were high (PSI2 = 93rd, PSI4 = 95th, PSI1 = 99th). We note, however, that PSI3 35th percentile ranking is due to her poor performance on both consistent and inconsistent words (see Table 5). Although large consistency effects are typical of SD, poor spelling for both consistent and inconsistent words is common for SD patients in advanced stages [15].

3.3. General discussion

The results demonstrate that there are distinct differences in spelling performance across younger adults, older adults, individuals with DAT, and individuals with PSI. The results from the homophone task suggest that there is an increased

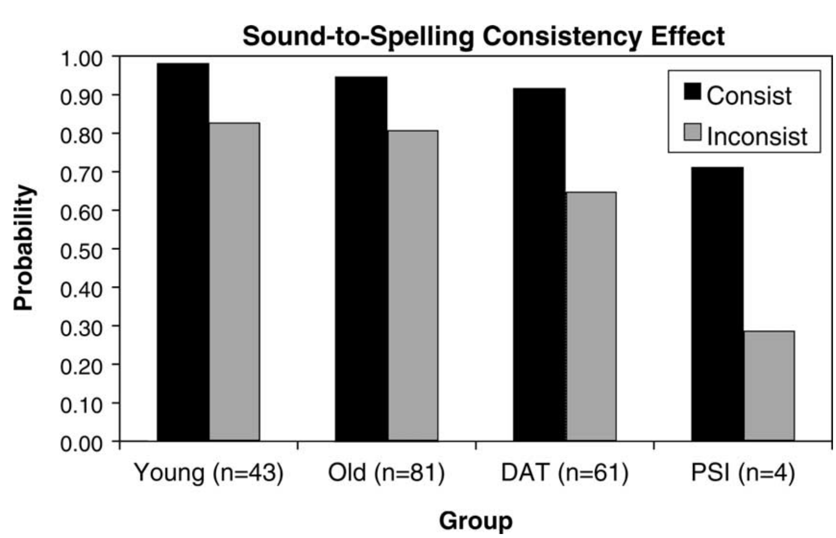

Fig. 8. Sound-to-spelling consistency effect—mean correct performance for consistent and inconsistent words.

reliance on semantics in healthy older adults and individuals with DAT, compared to the younger adults. Interestingly, the homophone data also indicate that the healthy older adults and the individuals with DAT produced relatively equivalent reliance on semantic information. This pattern can be contrasted with the individuals with PSI who, as expected, produced a decreased reliance on semantic information in homophone spelling. In addition, the results also provide evidence that the general behavioral profile of PSI can be produced by multiple etiologies including multiple infarcts (e.g. PSI3, see Section 2) and left anterior temporal atrophy that is more typical of semantic dementia (PSI1, PSI2, and PSI4; see [18]). We shall now turn to separate discussions of the implications of these results for changes in healthy older adults, individuals with early stage DAT, and individuals with PSI.

3.4. Age differences

The results of the homophone data (see Figs. 5 and 6) indicate that older adults rely more on semantics than younger adults. We believe that the most likely account of this pattern is that the division of labor between phonological and semantic pathways shifts during the aging process to more semantic processing. This shift in the division of labor should lead to a combination of a relative weakening of phonological-to-orthographic connections (in the PDP model) or sublexical processes (in the dual-route model) during aging (due to less use of this pathway) and a corresponding strengthening of semantic-to-orthographic connections (in the PDP model) or lexical processes (in the dual-route model) due to a greater use of this pathway. First, consider the possibility of a weakening of the connections between phonology and orthography (or sublexical processes) in older adults. At first glance, this would appear unlikely because the older adults produce quite comparable sound-to-spelling consistency effects as the younger adults in the present study. However, it is possible that there is a relatively larger input from semantics in older adults that compensates for the weakening of the connections between phonology and orthography. For example, Plaut et al. [32] have proposed that in normal readers, the semantic system contributes more to inconsistent words than consistent words. Similarly, in the dual-route model, the lexical route will contribute more to the spelling of inconsistent words than consistent words. Therefore, the weaker connections that exist between phonology and orthography for inconsistent words in older adults would allow for the opportunity for semantics in the PDP model or lexical processing in the dual-route model to contribute significantly more to word recognition and spelling performance. In fact, recent studies of reading aloud have shown that inconsistent words benefit more from semantic activation than do consistent words [10,11,41]. Of course, this compensatory argument is consistent with the larger influence of semantics in the homophone-spelling task in the older adults compared to the young adults.

Why would one expect a relative strengthening of the connections between semantics and orthography in older adults? This falls quite naturally from the additional 50 years of experience with the language. The relation between semantics and orthography is more arbitrary than the relation between phonology and orthography. For example, words with similar sounds tend to map onto similar spellings (e.g. *bunch*, *lunch*, *punch*, etc.) whereas words with similar meanings do not usually map onto similar spellings (e.g. *rum*, *vodka*, *gin*, etc.). Therefore, in order to become well established, the connections between semantics and orthography (or lexical processing) may be more experience-dependent than the connections between phonology and orthography (or sublexical processing). The model of Plaut et al. [32] suggests that learning to accurately translate spelling into phonology requires more training for words containing arbitrary relations (e.g. inconsistent words) than for words containing systematic relations (e.g. consistent words). The additional years of experience that older adults have had with words places them at an advantage in using the arbitrary relations between semantics and orthography. In addition, if one subscribes to the view that semantics is tied to the effects of word-frequency (e.g. [32]), the greater reliance on semantics for older adults in spelling is consistent with findings of larger frequency effects for older adults compared to young in experiments of reading aloud [4,39].

It is important to note that in the present analyses on low-frequency words, little evidence was found for the effects of aging in the accuracy data. In a recent study, MacKay and Abrams [24] observed aging effects for high-frequency difficult-to-spell words (e.g. *occurrence*), but no differences were observed for low-frequency, difficult-to-spell words (e.g. *calisthenics*). MacKay and Abrams suggested that the lack of a difference for low-frequency words represents an aging-familiarity tradeoff. That is, while younger and older adults are equally familiar with high-frequency words, older adults may be more familiar with low-frequency words than younger adults, and this compensates for any age-related deficit. The evidence from the present study suggests that this aging-familiarity tradeoff may be actualized as a greater reliance on semantic/lexical processing for older adults. Specifically, regarding the spelling of homophones, relative to younger adults, older adults spelled the homophone that corresponded to the dominant meaning more often when it also corresponded to a subordinate spelling.

3.5. Dementia of the Alzheimer's type versus primary semantic impairment

Turning to the spelling performance of individuals with DAT and PSI, the exaggerated consistency effect (more errors for inconsistent than consistent words; see Fig. 8) may have two distinct loci for these two groups. For the individuals with DAT, it is unlikely that the deficit in the spelling of inconsistent words has only a basis in semantic memory (PDP model) or lexical processing (dual-route model) for two reasons. First, individuals with DAT exhibit relatively intact semantic priming when attentional demands are minimized (see [27], for a review). This would suggest that there is some integrity of the underlying semantic network at least in early stage DAT. Second, individuals with DAT exhibit the same pattern of spelling of homophones as the healthy older adults in the current study (see Figs. 5 and 6). In this light, it may be that the exaggerated deficit in spelling inconsistent words arises because attentional control mechanisms are less able to select appropriate information and inhibit inappropriate information. That is, individuals with DAT are less able to access appropriate semantic representations when controlled processes are required. For example, given the pronunciation /plum/, individuals with DAT may have difficulty selecting the appropriate spelling generated by semantic/lexical processes (e.g. *plume*) and inhibiting the inappropriate spelling generated by phonological/sublexical processes (e.g. *ploom*). This perspective is further supported by lexical processing studies that have provided a dissociation between lexical and sublexical processes in DAT. Specifically, Balota and Ferraro [4] and Patterson et al. [29] have found that in a task that should primarily rely on lexical information (i.e. word naming), there is an increased reliance on the sublexical pathway in individuals with DAT. In addition, Balota and Ferraro [5] found that in a task that should primarily rely on sublexical information (i.e. rhyme decision for words and non-words), there is an increased influence of lexical information. This double dissociation would appear more consistent with an attentional selection framework that is dependent upon maintaining appropriate task demands, as opposed to breakdowns in the underlying representations (see [3], for a review). In contrast to individuals with DAT, the loss of semantic information in individuals with PSI makes meaning relatively unavailable. The result is a greater influence of phonological/sublexical information. This leads to the pattern of homophone spelling observed in Figs. 5–7 and also the exaggerated consistency effect as shown in Fig. 8.

It is important to note that in terms of the dual-route model, there are two non-semantic routes for spelling: (a) the lexical route via phonological to orthographic lexicons, and (b) the sublexical route. Thus, in terms of the dual-route model, an individual with a selective semantic impairment (i.e., the phonological and orthographic lexicons remained intact) could produce a spelling via either route (see [30,31]). The present data affords some information regarding the role of these two pathways in the present PSI individuals. Specifically, if the PSI individuals were primarily relying on a lexical route, via phonological to orthographic lexicons, then one would not expect a large breakdown in the spelling of inconsistent words. However, the present results suggest that the PSI individuals produced a disproportionate breakdown for inconsistent items, thereby suggesting that they were primarily relying on the sublexical route.

In contrast to the dual-route model, the PDP model does not contain lexical representations as typically conceived. Thus, if semantic processing were necessary in order to generate the correct spelling for inconsistent words, then damage to the semantic system would always lead to a deficit in spelling inconsistent words, as found in the present study. Interestingly, and consistent with the dual-route model, there are reports in the literature of individuals with semantic deficits that do not have problems reading[4] inconsistent words (i.e. words with inconsistent mappings from orthography and phonology (see [7,23]). The PDP model can account for these findings if one assumes that for certain individuals, the orthographic-to-phonological computation is sufficient to generate the correct reading (or spelling) of inconsistent words [15]. In terms of the current study, none of our PSI patients would fall into the category of semantically impaired with normal inconsistent word spelling. In other words, all of these individuals have considerable difficulty spelling inconsistent words compared to healthy older adults. Thus, although our PSI individuals do not appear to use lexical but non-semantic spelling, our data do not speak to the issue of whether lexical but non-semantic spelling is possible in some individuals.

The present data do suggest differences across individuals with PSI that appear to correspond to differences in underlying neuropathology. Consider the spelling performance of low-frequency words by PSI3, who presented with multiple lacunar infarcts. This individual was far less accurate than the other participants with regard to spelling for consistent words (Table 5, bottom panel). Interestingly, it is not uncommon for individuals with SD to exhibit profound deficits for low-frequency consistent words in the later stages of dementia [15]. In fact, Graham et al. [15] found that in the later stages of SD, low-frequency and medium-frequency consistent words were misspelled at about the same rate as low-frequency inconsistent words. Again, it appears that different etiologies (multiple lacunar infarcts versus anterior temporal lobe atrophy in individuals with SD) can be manifested in similar ways on overlapping tasks.

In addition to the spelling data, there are a number of other intriguing aspects of the individuals with PSI. In particular, these individuals were initially identified from a large pool of healthy older adults and individuals with DAT based on a pre-existing battery of neuropsychological tests. As shown in Fig. 1, these individuals were quite discontinuous on the semantic and non-semantic measures compared to the remaining subjects. Moreover, this pattern of psychometric performance predicted asymmetric atrophy (PSI1, PSI2, and PSI4) or damage (PSI3). It is thus noteworthy that a gross distinction based on standard psychometric tests on a large cohort of individuals can identify individuals with atypical structural MRI profiles.

Of course, the final diagnosis of a non-DAT type dementia in these four individuals must await autopsy results. Moreover, the variance in etiology may further subdivide their

[4] We are unaware of any individuals that have semantic deficits and intact spelling for inconsistent words.

diagnosis. We speculate that PSI1 and PSI4 are likely to be classified as SD as outlined by Hodges and coworkers, PSI2 as probable, and PSI3 as unlikely. It seems more likely that PSI3's lacunar infarcts damaged regions projecting to those showing focal atrophy in more traditional cases of SD. Although there were some differences across these four individuals, the similarity in spelling patterns across a number of classes of items is quite striking.

It should also be noted here that there is accumulating evidence that there are distinct patterns of neuropathology across individuals with Alzheimer's disease and that these patterns may be related to psychometric performance. Specifically, Kanne et al. [20] found that a relatively high burden of senile plaques (based on autopsy reports) in frontal, parietal, and medial temporal areas was directly related to relatively poor performance on psychometric tasks that reflected frontal, parietal, and medial temporal areas, respectively. Thus, there is considerable heterogeneity in the disease profile, and this heterogeneity may contribute to the present distinct subtypes.

4. Summary

The present study affords a unique comparison of spelling performance across four distinct groups of individuals using the same set of stimuli that varies semantic and phonological-to-orthographic correspondences. The results of the homophone-spelling task indicate that there are large differences in the use of semantics by the PSI individuals, with relatively normal performance in the individuals with DAT. This pattern, coupled with the relatively large breakdowns in spelling inconsistent sound-to-spelling words in both individuals with DAT and PSI, suggests that the breakdown in inconsistent words observed in demented adults may have different bases in DAT and PSI. These results highlight the importance of the coordination of multiple sources of semantic, orthographic, and phonological information during spelling performance.

Acknowledgements

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Appendix A

Homophones			
Meaning-dominant-spelling dominant		Meaning-dominant-spelling subordinate	
Waste		Pear	
Peak		Bale	
Peer		Plane	
Tail		Vein	
Ate		Days	
Nun		Wrap	
Mall		Bored	
Meat		Some	
Current		Capitol	
Manner		Naval	
Consistent words		Inconsistent words	
Pulp	Mound	Plume	Plaid
Branch	Slick	Nil	Yacht
Scalp	Split	Odd	Ache
Mount	Scrub	Shriek	Ski
Welsh	Cab	Roar	Niche
Garb	Slug	Pert	Bead
Bulk	Swell	Newt	Sieve
Babe	Prong	Dirge	Pearl
Elk	Flog	Hype	Crepe
Leash	Crust	Cheese	Gauge
Void	Hunch	Soap	Ghoul
Bulb	Trump	Hurl	Womb
Belch	Lag	Zinc	Soup
Cusp	Fang	Lewd	Tongue
Filth	Tuck	Pyre	Monk

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