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A Dissociation of Frequency and Regularity Effects in Pronunciation Performance across Young Adults, Older Adults, and Individuals with Senile Dementia of the Alzheimer Type

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The regularity of a given spelling-to-sound sequence in English primarily influences the ease of naming low-frequency words and produces little influence on the ease of naming high-frequency words. This frequency × regularity interaction has been accommodated within both a single-route connectionist model and dual-route models of pronunciation performance. Recent evidence presented by dual-route theorists suggests that the sublexical route in naming performance demands more attention than the lexical route. The present study further explores this possibility by investigating the word-frequency by regularity interaction across five different groups of subjects that have well-documented changes in attentional capacities. The five groups were healthy young adults, older adults between 60 and 80 years of age, older adults greater than 80 years of age, very mildly demented individuals with senile dementia of the Alzheimers Type (SDAT), and mild/moderately demented SDAT individuals. The response latency results from a simple word-naming experiment indicated that there was a consistent increase in the word-frequency effect across the five subject groups (from young to mildly demented individuals) without any corresponding increase in either the regularity effect or the frequency × regularity interaction. However, the results also indicated that there was an increased likelihood of regularization errors (e.g., pronouncing the word *pint* such that it rhymes with *hint*) across the subject groups. These results are viewed as most consistent with a model in which healthy young adults are especially slow to name low-frequency irregular words because they must inhibit inconsistent output from an assembled route and produce the correct output from the addressed route. We argue that the increased likelihood of regularization errors in the healthy aged individuals and to a greater extent in the SDAT individuals may be due to a breakdown in the inhibitory control of partially activated (assembled route) information.

Within the past decade, there has been considerable interest in the notion that there are two distinct routes to pronouncing a word aloud, an addressed route and an assembled route (see Coltheart, 1978; Humphreys & Evett, 1985, for reviews). In the addressed (lexical) route, the reader maps the orthographic string onto a lexical representation and then accesses the programs necessary for naming the word aloud. In the assembled (sublexical) route, the reader presumably relies on the regularities in the spelling-to-sound correspondences within a language to assemble the pronunciation into consistent phonological elements and then concatenates these elements to arrive at a pronunciation. One piece of evidence that has been viewed as consistent with this framework is the difference in pronunciation performance across orthographies that differ with respect to the regularity of the orthography-to-phonology (O–P) correspondences. In cases where the alphabetic system is relatively unequivocal in mapping orthography to phonology, as in Serbo-Croatian, one finds little or no influence of lexical variables (e.g., word-

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frequency and lexicality) in speeded naming performance (see Frost, Katz, & Bentin, 1987). The notion here is that the reader can rely totally on the assembled route, because it always produces the correct pronunciation of the letter string. However, in English, and to a greater extent in deeper orthographies such as in Hebrew, the mapping between orthography and phonology is far less transparent. For example, in English, the word *pint* involves an inconsistent mapping of orthography to phonology because all other *int* words (e.g., *mint, lint, tint*) rhyme with *hint* not *pint*. In addition, there are other orthographic strings such as *colonel, tongue,* and *aisle* that appear to be relative hermits of O–P correspondences, because there are virtually no other words that have such correspondences. Because of the inconsistencies of O–P correspondences in English, it would appear that subjects must map the whole orthographic string onto a lexical representation to name these words aloud. Thus, one should expect increasing influences of the lexical route in speeded naming performance (as reflected by word frequency and lexicality effects) as one decreases the transparency of the O–P correspondences across orthographies (also referred to as orthographic depth). This is precisely the pattern reported by Frost et al.

If the lexical route appears to be necessary in relatively opaque orthographies, such as in English, then one might ask what evidence is there for a role for the assembled route. Why would subjects ever use an assembled route to name an English word aloud? One piece of evidence that researchers originally identified as being consistent with an assembled route is the relative ease with which individuals can name nonwords aloud. Because nonwords do not have a direct lexical representation, it would appear that a nonlexical route is used to name nonwords aloud. However, this piece of evidence was soon disabled by evidence from activation–synthesis approaches (e.g., Glushko, 1979; Kay & Marcel, 1981; Marcel, 1980) in which the pronunciation of a nonword can be generated by the activation of similarly spelled words.

A second, and more powerful, line of support for the role of an assembled route in English comes from case studies of acquired dyslexics. These studies appear to provide evidence for a double dissociation between the two routes. Specifically, one class of acquired dyslexics, *surface dyslexics,* produce a selective breakdown in the lexical route, but have an intact assembled route. These individuals are likely to regularize irregular words and exception words, e.g., they might pronounce *broad* such that it sounds like the regular pronunciation of the nonword *brode* (e.g., Marshall & Newcombe, 1973; McCarthy & Warrington, 1986; Shallice, Warrington, & McCarthy, 1983). A second class of acquired dyslexics, *phonological* (deep) *dyslexics,* appear to have an intact lexical route but an impaired phonological route. These individuals can pronounce irregular words and other familiar words that have lexical representations; however, when presented a nonword that does not have a lexical representation then there is considerable breakdown in performance (Patterson, 1982; Shallice & Warrington, 1980). The argument here is that the phonological dyslexics have a selective breakdown in the assembled route. The double dissociation between assembled and lexical routes has been viewed as some of the most powerful evidence supporting the dual-route model.

Although it would appear that the dual-route model is well entrenched in the literature, there is an intriguing alternative single-route connectionist model developed by Seidenberg and McClelland (1989) that does an excellent job of handling some of the major findings in the word recognition literature. The model is appealing because of its relative simplicity and because of its quantitative nature. The model involves a set of input units that code the orthographic input of the stimulus and a set of output units that represent the phonology entailed in the naming response. All the input units are connected to a set of hidden units and

all of the hidden units are connected to the set of output units. The weights in the connections across these three layers have no organized mapping between orthography and phonology before training. On each trial during training, the model is presented an orthographic string. The model then computes some phonological output that at first is likely to have very little similarity to the correct output. However, across training trials, the weights in the connections are adjusted via the back-propagation rule in order to reduce the difference between the correct pronunciation and the models output on a subsequent trial. During training, Seidenberg and McClelland presented the model with 2897 English monosyllabic words at a rate that was monotonically related to the estimated frequency of occurrence of the words in printed English, based on the Kucera and Francis (1967) norms. The exciting result of this endeavor is that the model does a rather good job at producing the phonology that corresponds to regular words, high-frequency exception words, and even nonwords that the model was never trained on. Although there is some controversy regarding the degree to which the model actually captures some aspects of the data (e.g., see Besner, Twilley, McCann, & Sergobin, 1990), the fact that it provides a quantitative account of aspects of simple word naming performance (without either O–P "rules" or a lexicon) is quite intriguing and presents a powerful challenge to available word-recognition models. In fact, even if there are inadequacies in the implemented model, it is at least possible that future instantiations of this model may eliminate some of these problems.

The present study focuses on one of the central empirical findings in recent discussions of dual-route and single-route models of naming performance; specifically, the frequency by regularity interaction (e.g., Andrews, 1982; Monsell, Patterson, Graham, Hughes, & Milroy, 1992; Paap & Noel, 1991; Seidenberg, Waters, Barnes, & Tanenhaus, 1984). The finding here is that for high-frequency words, there is very little influence of O–P correspondence, whereas, for low-frequency words there is a relatively large influence of O–P correspondence. The dual-route model accommodates this finding by assuming that for high-frequency words the lexical route is faster than the assembled route, and hence, any inconsistent information from the assembled route for exception words does not arrive in time to compete with the lexical route and hence does not influence naming latencies. However, if one slows up the lexical route by presenting a low-frequency word, then one finds that the assembled output has time to interfere with the lexically mediated route and hence response latency increases. The important point for the dual-route model is that the output of a low-frequency lexically mediated response can be interfered with by the availability of inconsistent phonological information that is produced via the assembled route.

Interestingly, one of the most powerful demonstrations of the Seidenberg and McClelland single-route model is that it also nicely produces the frequency by regularity interaction by assuming only one route in naming performance. The results of the simulations indicate that the error scores produced by the model for high-frequency regular words and exception words are quite comparable, however, for low-frequency words, the error scores are worse for exception words than for regular words. (The assumption being that error scores map onto response latencies.) Thus, one does not have to assume separate routes to accommodate the frequency by regularity interaction, but rather, this effect appears to fall quite naturally from the correspondences between the frequency of particular O–P correspondences in a given orthography.

The present study will attempt to provide further evidence regarding the mechanisms underlying the frequency by regularity interaction by investigating this interaction across five groups of subjects that have particular characteristics that might modulate this interaction in an intriguing fashion. The

five groups include young adults, older adults between the ages of 60 and 80 years of age, older adults greater than 80 years of age, very mildly demented individuals with senile dementia of the Alzheimer Type (SDAT), and mild/moderately demented individuals with SDAT. A comparison of the word frequency by regularity interaction across these five groups of subjects is of interest for three reasons: First there is clear evidence in the literature that there are breakdowns in attention-demanding tasks across young and older healthy adults (Balota, Black, & Cheney, 1992; Hasher & Zacks, 1979, 1988; Plude & Hoyer, 1985; Salthouse, 1984, see review by Hartley, 1992) and also between healthy older adults and SDAT individuals (Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986; Graf, Tuokko, & Gallie, 1990; Jorm, 1986; Nestor, Parasuraman, Haxby, & Grady, 1991). The importance of investigating the word-frequency by regularity interaction across groups that have varying attentional capacities is that there have been recent arguments that the two routes demand differing amounts of attentional capacity. For example, Paap and Noel (1991) have argued that the assembled route may demand more attentional resources than the lexical route because the assembled route involves an attention-demanding constructive process in which subword units must be assembled and organized into an acceptable output. In support of this argument, Paap and Noel found that modulating the demands of a secondary task had an intriguing influence on the naming performance of low-frequency exception words: low-frequency exception words were actually *facilitated* by the presence of a high memory load compared to the presence of a low memory load (also see Bernstein & Carr, 1991). On the other hand, high-frequency exception and consistent words, along with low-frequency consistent words all produced slower response latencies under the presence of a high memory load compared to a low memory load conditions. Paap and Noel argued that because the assembled route is more attention demanding than the lexical route, it is more influenced by the presence of a high memory load. This would have the influence of decreasing the interference from the assembled route for the low-frequency words. Hence, the speed of naming these words is actually facilitated under high memory load compared to low memory load. This finding is quite intriguing because it suggests that under some, predictable circumstances one can actually facilitate performance via the presentation of a secondary task. This finding is also important because it is unclear how a single-route model might accommodate such a pattern. The interesting issue with respect to the present study is that if the assembled route demands more attentional capacity than the lexical route, then it is possible that there will be a decreased influence of the assembled route across groups of subjects that have decreasing attentional capacities. More specifically, there should be a decreasing deleterious effect of inconsistent O–P correspondence, compared to consistent O–P correspondence, across groups of subjects that have decreased attentional capacities.

The second reason that an investigation of the word frequency by regularity interaction across these subject groups may be quite informative is because of recent arguments and evidence that there is an increasing breakdown in the ability to inhibit partially activated but inappropriate information across these subject groups. For example, there is now evidence from the negative priming paradigm (e.g., Hasher, Stoltzfus, Zacks, & Rympa, 1991; McDowd & Oseas-Kreger, 1991; Tipper, 1991) that healthy older adults do not appear to inhibit irrelevant information as much as healthy young adults. Moreover, Balota and Duchek (1991) have recently reported evidence that indicates that SDAT individuals show a reduced ability to inhibit irrelevant meanings of contextually biased homographs, compared to healthy older adults (also see Duchek, Balota, Ferraro, Gernsbacher, Faust, & Conner, 1992). Thus,

there is evidence that there are breakdowns in inhibitory processes across these five subject groups. If there is a decrease in inhibitory processes across these groups, then there may be increased difficulty across our subject groups in inhibiting the output from the assembled route for items that produce conflicting lexical and assembled output, i.e., exception words. This would predict an increase in regularization errors (e.g., pronouncing *pint* such that it rhymes with *hint*) across subject groups that have increasing breakdowns in inhibitory control processes.

The third motivation for investigating changes in the frequency by regularity interaction across these groups of subjects deals with predictions from general slowing models of cognition. A number of researchers have argued that data from reaction time tasks across healthy young and older adults can be accommodated by a general slowing function (Birren, 1974; Cerella, 1985; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Salthouse, 1985). According to this approach, because all processes are assumed to slow at a constant rate in older adults, one should expect effect sizes in older adults to be proportional to effect sizes in younger adults. For example, Myerson et al. have argued that response latencies for older adults across conditions in large part can be predicted by a relatively simple linear function (older adults RT = younger adults RT * 1.5). Based on such general slowing arguments, one might expect that the word frequency effect, regularity effect, and word frequency by regularity interaction should all proportionally increase in healthy older adults compared to younger adults by a factor that is akin to 1.5. Furthermore, it is worth noting here that Nebes and Brady (1992) have recently extended the same general slowing argument to SDAT individuals, compared to healthy age-matched controls. Thus, there should be similar proportional increases in these effects between the demented and nondemented age-matched healthy older adults. In general, overall response latency should increase across groups along with proportional increases in the effect of frequency, regularity, and the frequency by regularity interaction.

In this light, it is also interesting to note that the Seidenberg and McClelland (1989) single-route connectionist model might also predict larger effects of frequency, regularity, and the frequency by regularity interaction across our subject groups. Of course, this depends upon how one might represent the aging and disease process within their connectionist model. Seidenberg and McClelland do provide some information regarding the effect of at least one type of network damage. That is, in order to capture some of the characteristic reading difficulties in developmental dyslexia, Seidenberg and McClelland decreased the number of hidden units from 200 to 100 in one of their simulations (see p. 547). The results indicated that, with this type of damage, the frequency effect, regularity effect, and, at least to some extent, the frequency by regularity interaction appear to increase (see Fig. 21, of the Seidenberg & McClelland paper). Although there are clearly alternative ways to damage such a model, the fact that frequency, regularity, and the interaction of these two variables reflect patterns of activation across the same set of hidden units would appear to suggest that the effect of these factors would move together across our subject groups.

Finally, in anticipation of the results, an important aspect of the present study is the extent to which frequency and regularity produce parallel changes in effect size across the groups of subjects. That is, based on unembellished dual-route models (i.e., models that do not predict differing attentional demands of the addressed and assembled routes) and single-route models, one would expect increasing effects of O–P correspondences as one finds increasing effects of word frequency. Because these two effects are intimately tied, one should not find a change in the effect size of one variable across our subject groups without a

corresponding change in the effect size of the second variable. Thus, if there is an increasing frequency effect across our subject groups one should also find an increasing regularity effect and also an increasing frequency by regularity interaction.

METHOD

Subjects

A total of 157 subjects participated in the study. With the exception of the 25 young adults, all subjects were recruited from the Washington University Alzheimer's Disease Research Center (ADRC). The participants were originally screened for depression, severe hypertension, reversible dementias, and any other potential disorders that could affect cognitive performance. Inclusionary and exclusionary criteria for SDAT conform to those outlined in the NINCDS–ADRDA criteria (McKhann, Drachman, Folstein, Katzman, Price, & Stadlan, 1984). Dementia severity was staged in accordance with the Washington University Clinical Dementia Rating (CDR) scale (Berg, 1988; Hughes, Berg, Danziger, Coben, & Martin, 1982). In this scale a score of 0 indicates no dementia; a score of .5 indicates very mild, or "Questionable," dementia; a score of 1.0 indicates "Mild" dementia; and a score of 2.0 indicates "Moderate" dementia.

The CDR is based on a 90-min interview that assesses cognitive ability in areas including memory, orientation, judgement and problem solving, community affairs, hobbies, and personal care. Both the patient and his or her collateral source (e.g., spouse, child) participate in the interview. One of eight board-certified physicians (four neurologists, four psychiatrists) conducted these interviews, which were videotaped and subsequently reviewed by a second physician for reliability. The diagnosis of AD by this research team has been excellent, with 103 out of 107 (96%) individuals diagnosed as having SDAT having AD confirmed at autopsy (Berg, Smith, Morris, Miller, Rubin, Storandt, & Coben, 1990; Burke, Miller, & Rubin, 1988; Morris, McKeel, Fulling, Torack, & Berg, 1988, Morris, Mohs, Rogers, Fillenbaum, & Heyman, 1988).

Of the 132 participants obtained from the ADRC, 70 participants did not present any symptoms of dementia (CDR = 0). Within this group of 70 participants, 35 individuals were in the young–old group (mean age = 71, *SD* = 6.7) and 35 individuals were in the old–old group (mean age = 84, *SD* = 3.3). There were 29 participants diagnosed as CDR .5 which is a group that appears to be in the very early stages of AD (mean age = 74, *SD* = 9.4). In fact, in a recent longitudinal study, 11 of 16 subjects originally classified as having very mild dementia (CDR = .5) by this research team actually progressed to a more severe stage of SDAT over the course of 84 months or had AD positively confirmed at autopsy (Rubin, Morris, Grant, & Vendega, 1989). There were 33 participants in the mild/moderate group (mean age = 75, *SD* = 7.9). Within this group there were 20 individuals diagnosed with a CDR = 1.0 (mild dementia) and 13 diagnosed with a CDR = 2.0 (moderate dementia). We collapsed across the mild and moderate groups in order to better equate the sample sizes across our subject groups. Moreover, preliminary analyses indicated that there were very little differences between the mildly and moderately demented subjects. Finally, there were 25 young adults that were recruited from undergraduate courses at Washington University.

Apparatus

All testing was conducted with an Apple IIe microcomputer that was interfaced with a Mountain Hardware clock card that provided an estimate of response latency to the nearest millisecond. A Gerbrands G1341T Electronic Voicekey was interfaced with the computer to detect the onset of vocalization.

Materials

The critical stimuli were the same as those used by Seidenberg et al. (1984, Ex-

periment 4). These stimuli were selected because (a) there is already evidence that these stimuli produce the desired frequency by O–P correspondence interaction in naming performance and (b) there are three levels of O–P correspondence. There were 15 words in each of six conditions that were produced by factorially crossing three levels of O–P correspondence (regular vs inconsistent vs unique) with two levels of word frequency (high vs low). Regular and inconsistent words include spelling patterns that appear in many words, with the major difference being whether the phonology corresponding to a given spelling pattern is consistent across words (regular) or inconsistent across words. The words listed in the unique category are words such as *colonel*, which have very few, if any, similar O–P correspondences. As reported in Seidenberg et al., the median frequencies for the high-frequency regular, inconsistent, and unique words were 638, 672, and 707, respectively, whereas the corresponding frequency values for the low-frequency regular, inconsistent, and unique words were 18, 24, and 17, respectively (Carroll, Davies, & Richman, 1971). Further details regarding this set of stimuli are available in Seidenberg et al. Finally, in addition to the critical target words, there were 38 medium- to high-frequency regular words that were selected for practice and buffer items.

Procedure

After subjects were familiarized with the testing apparatus, they were given instructions about the task. Subjects were told that on each trial a word would appear in the center of the computer screen and they were to name that word aloud as quickly and as accurately as possible. After the instructions, subjects were given 30 practice trials, which were followed by two test blocks of 49 words. The first 4 trials of each test block were buffer trials, which were then followed by 45 critical target words.

The following sequence occurred on each trial: (a) a row of three asterisks (***) was presented in the center of the screen for 350 ms; (b) a blank screen was presented for 275 ms; (c) a word was presented in the center of the screen; (d) the subject's pronunciation of the word triggered the computer to erase the screen; (e) the experimenter pressed a key on the keyboard indicating the type of response that was produced; specifically, the "0" key was pressed when the subject produced the correct response, the "1" key was pressed when the subject produced an unrelated word or some other extraneous sound (e.g., a cough) triggered the computer, and the "5" key was pressed when the subject produced (or attempted) a regularization of the word, e.g., pronouncing *pint* such that it rhymed with *tint;* (f) a 2-s intertrial interval.

Each subject was tested individually with an experimenter present. The subject sat at a comfortable distance from the CRT.

Design

The experiment is a group (young vs young–old vs old–old vs very mildly demented vs mild/moderately demented) × frequency (high vs low) × O–P correspondence (regular vs inconsistent vs unique words) mixed-factor design. Group is the only between-subjects factor. There are three dependent measures: mean onset latencies, mean percentage errors, and mean percentage regularizations. A regularization error here is defined as the mispronunciation of a word that conforms to an O–P correspondence for the whole word, e.g., pronouncing *pint* such that it rhymes with *hint*, or, on rare occasions, an attempted regularization, e.g., pronouncing *weld*, such that it sounds like *wheeled*.

Psychometric Test Performance

Each participant enrolled in the ADRC was also administered a 2-h battery of psychometric tests designed to assess psychological functions including memory, language, psychomotor performance, and intelligence. Memory performance was assessed via the following: Wechsler Memory Scale (WMS; paired-associate learning; Wechsler & Stone, 1973), Benton Visual

TABLE 1
MEANS AND STANDARD DEVIATIONS (IN PARENTHESES) OF THE PSYCHOMETRIC TESTS AS A FUNCTION OF SUBJECT GROUP

Test	Subject group			
	Young–old	Old–old	Very mild SDAT	Mild/moderate SDAT
Logical	10.24	8.14	5.17	1.60
Memory	(2.84)	(2.22)	(2.93)	(1.68)
Mental	7.47	7.40	6.17	3.28
Control	(1.99)	(1.68)	(2.56)	(3.06)
Associate	14.15	13.60	10.57	4.96
Recall	(3.87)	(3.55)	(3.99)	(3.52)
Benton Delay, number correct	6.32	5.54	4.62	1.46
	(1.89)	(1.70)	(2.01)	(1.50)
Benton Copy, number correct	9.79	9.26	9.17	5.75
	(.59)	(1.31)	(1.31)	(3.99)
Benton Recall, errors	5.94	8.09	11.03	18.63
	(3.15)	(3.99)	(5.55)	(6.32)
Benton Copy, errors	.24	.71	.86	8.63
	(.70)	(1.32)	(1.38)	(10.41)
Trails, Form A	41.79	56.22	58.45	69.72
	(17.07)	(29.14)	(29.88)	(64.21)
WAIS Information	21.65	20.74	16.97	8.12
	(4.40)	(4.31)	(5.09)	(4.93)
WAIS Block Design	33.21	28.29	23.24	9.40
	(9.10)	(7.79)	(10.79)	(10.78)
WAIS Digit Symbol	48.71	40.66	35.36	13.76
	(13.62)	(12.03)	(12.57)	(15.50)
Boston Naming Test	56.03	52.66	49.52	30.20
	(4.18)	(7.27)	(9.07)	(15.72)
Word Fluency (S + P)	33.00	29.91	25.28	12.32
	(12.79)	(10.21)	(8.58)	(9.78)
Digit Span (F + B)	12.03	11.71	10.62	7.68
	(2.69)	(2.15)	(1.80)	(3.60)

Retention Test (picture memory; Benton, 1963), WMS Logical Memory (surface-level story memory), and WMS forward and backward digit span. Adult intelligence was assessed using the following subtests of the Wechsler Adult Intelligence Scale (WAIS): Information, Comprehension, Block Design, and Digit Symbol (Wechsler, 1955). Visual–Perceptual–Motor performance was assessed by the Benton Copy Test and Trail Making–Form A. In the Benton Copy Test, participants copied a geometric figure; in Trail Making–Form A, participants connected numerically-ordered dots that resulted in a specified pattern (Armitage, 1946). In addition, participants also received the WMS Mental Control test which evaluates the ability to quickly produce a well-rehearsed letter or digit sequence, such as the alphabet, in a specified amount of time. Participants also received the Word Fluency test, which allows investigation of processes associated with lexical retrieval (Thurstone & Thurstone, 1949). In this task, subjects are required to quickly generate as many words beginning with a specified letter (P or S) in an allotted time period (60 s per letter). All subjects provided data for all tasks, with the exception of one moderately demented individual, who did not complete any of the four Benton tasks, the Associate Recall task, or the WAIS Digit Symbol task.

As shown in Table 1, across the four groups that were obtained from the ADRC, there are clear effects of group on each of the psychometric tests. In separate analyses of variance (ANOVAs) that tested the

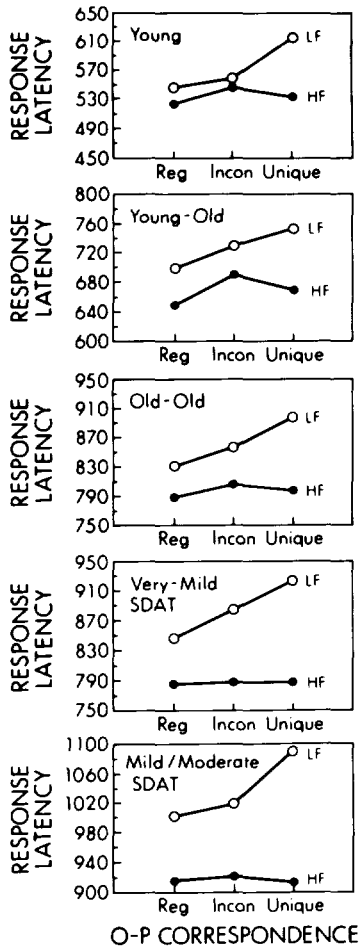

FIG. 1. Mean response latencies (ms) as a function of group, word frequency, and O–P correspondence.

main effect of group on each test, there were reliable main effects of group for each of the psychometric tests with all $ps < .0001$, with the exception of Trails Form A which produced a main effect of group with $p < .05$. Hence, our contention that there are rather widespread cognitive breakdowns across these groups is substantiated.

RESULTS

In analyzing the data, we first categorized each response as correct, incorrect, or a regularization. For the correct responses, we then calculated the mean response latency and *SD* for each subject across items and also for each item across subjects within a group. In order to decrease the likelihood that these analyses would be disproportionately influenced by extreme response latencies, any observation that was greater than 2.5 *SD*s above or less than 2.5 *SD*s below the subject mean (for the subject analyses) or the item mean for a given group of subjects (for the item analyses) was treated as an outlier. In addition, if an observation was less than 150 ms or greater than 2500 ms the observation was also treated as an outlier. The percentages of responses screened by this procedure were 2.1 (young), 3.8 (young–old), 3.6 (old–old), 3.8 (very mildly demented), and 5.2% (mild/moderately demented). For each cell, we then calculated subject and item mean response latencies (excluding outliers), subject and item mean percentage errors (including outliers, but excluding regularizations, e.g., producing *pint* such that it rhymes with *hint*), and subject and item mean percent regularizations. For each of these dependent variables a 5 (group) × 2 (frequency) × 3 (O–P correspondence) mixed-factor ANOVA was conducted. Unless otherwise specified, any effects referred to as significant have *p*-values at least less than .05.

Mean Response Latencies

Figure 1 displays the mean response latencies (based on subject means) as a function of group, frequency, and O–P correspondence. There are seven points to note in Fig. 1. First, response latency increases systematically across subject groups, $F_1(4,152) = 21.72$, $p < .001$, $F_2(4,420) = 597.59$, $p < .001$. Second, low-frequency words produced slower onset latencies than high-frequency words, $F_1(1,152) = 165.95$, $p < .001$, $F_2(1,420) = 159.90$, $p < .001$, for each of the subject groups. Third, again for each subject group, unique words produced slower response latencies than both inconsistent words and regular words, $F_1(2,304) = 31.87$, $p < .001$, $F_2(2,420) = 13.30$, $p < .001$. Fourth, and interestingly, one can see that the frequency effect increases systematically across groups, going from the young to the mild/moderately demented in-

dividuals, $F_1(4,152) = 6.15$, $p < .001$, $F_2(4,420) = 3.18$, $p = .01$. Fifth, there is relatively little evidence of an increase in the O–P correspondence effect across groups, $F_1(8,304) = .55$, $F_2(8,420) = .62$. Sixth, the influence of O–P correspondence is greater for low-frequency words than high-frequency words, $F_1(2,304) = 27.94$, $p < .001$, $F_2(2,420) = 10.18$, $p < .001$. Thus, as predicted by both dual-route models and single route models, O–P correspondence has a much larger effect for low-frequency words than for high-frequency words. Seventh, and importantly, there is no evidence of a group by frequency by O–P correspondence interaction, $F_1(8,304) = .83$, $F_2(8,420) = .43$. Thus, the intriguing aspect of these data is that there is both a group × frequency interaction and a frequency × O–P correspondence interaction; however, there is no evidence of either a group × O–P correspondence interaction or a group × frequency × O–P correspondence interaction.

One of the points that should be highlighted in Fig. 1 is that the frequency × O–P correspondence interaction is primarily produced by the presence of the unique words. More specifically, even though there are highly reliable frequency × O–P correspondence interactions in the overall analysis, if one only considers the influence of consistency (regular vs inconsistent words) the size of this effect is remarkably similar across subject groups for high-frequency (17 ms) and low-frequency (19 ms) words, both item and subject F's < 1.00 for the frequency × consistency interaction. Thus, there is no evidence that the effect of consistency is being modulated by frequency across a wide range of naming performance across these five groups of subjects.

In order to more clearly display the different effects of frequency and O–P correspondence across our subject groups, we display in Fig. 2 the mean frequency effects (low-frequency minus high-frequency words), mean consistency effects (inconsistent minus regular words), and mean uniqueness effects (unique minus regular words) as a function of subject group. As one can clearly see in Fig. 2, there is an increasing frequency effect across subject groups, whereas, both the consistency and the uniqueness effects are relatively constant across subject groups.

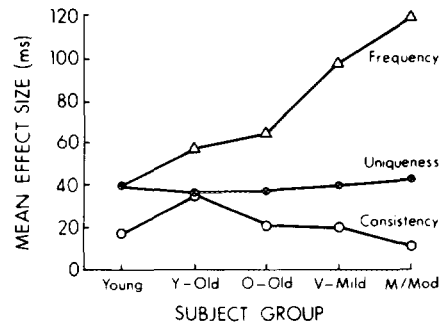

FIG. 2. Mean frequency (high frequency minus low frequency), consistency (inconsistent minus regular), and uniqueness (unique minus regular) effects in response latency (ms) as a function of group.

Percentage Errors

Figure 3 displays the mean percentage errors (including extraneous triggering of the voicekey and outliers but excluding regularizations) as a function of group, frequency, and O–P correspondence. There are five points to note in Fig. 3. First, errors systematically increased from the healthy young individuals to the mild/moderately demented individuals, $F_1(4,152) = 12.49$, $p < .001$, $F_2(4,420) = 34.41$, $p < .001$. Second, one can see that overall there were more errors on low-frequency words than high-frequency words, $F_1(1,152) = 141.20$, $p < .001$, $F_2(1,420) = 69.01$, $p < .001$. Third, there were more errors on unique words than on either regular words or inconsistent words, $F_1(2,304) = 57.26$, $p < .001$, $F_2(2,420) = 21.23$, $p < .001$. Fourth, there is again evidence of an interaction between frequency and O–P consistency such that there is a relatively high error rate primarily for the unique low-frequency words, $F_1(2,304) = 35.65$, $p < .001$, $F_2(2,420) = 11.21$, $p < .001$. Fifth, the influence of word frequency again appears to increase across groups but now it primarily increases for

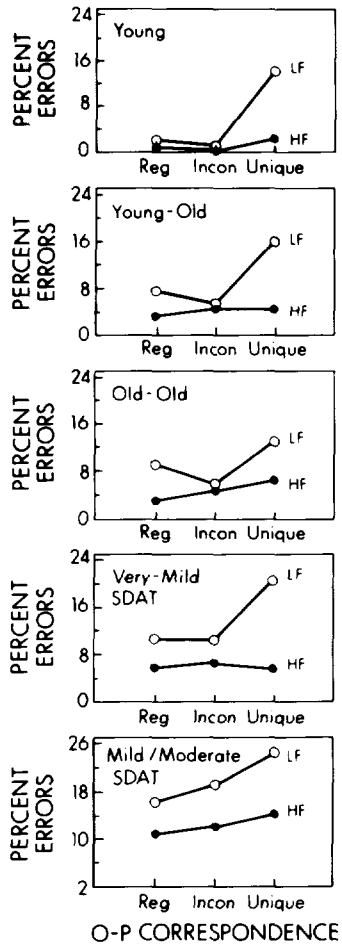

FIG. 3. Mean percentage errors as a function of group, word frequency, and O–P correspondence.

the regular and inconsistent words, with relatively little increase for the unique words. Although the group × frequency × O–P correspondence reached significance in the subjects analysis, $F_1(8,304) = 2.44$, $p = .014$, it did not approach significance in the items analysis, $F_2(8,420) = .83$. Although the effects are smaller, the results from the error analyses overall conform to the analyses performed on the response latency data, i.e., there is some evidence of an increasing influence of word frequency across groups, especially for the regular and inconsistent words, but there is no evidence of an increasing influence of O–P correspondence across groups. Thus, there is no evidence of a speed–accuracy tradeoff. In fact, mean error rate and mean response latencies were overall highly and positively correlated across conditions, $r = .79$.[1]

It should also be noted here that the interaction between frequency and O–P correspondence is primarily produced by the presence of the unique word condition. As shown in Fig. 3, the influence of consistency (regular vs inconsistent words) across groups is virtually identical for high-frequency (.8%) and low-frequency (−.6%) words, both item and subject Fs < 1.00. Thus, as with the response latency data, the error data provide no evidence that the influence of consistency is being modulated by frequency.

Percentage Regularizations

Figure 4 displays the mean percentage of regularizations as a function of group, frequency, and O–P correspondence. The major point to note in Fig. 4 is the rather striking increase in the regularization errors across subject groups especially for the unique low-frequency words. This localized increase in regularization errors con-

[1] Separate analyses were also conducted on only the percentage of outliers to insure that the analyses on the response latencies were not due to differential trimming of observations from certain conditions for specific groups. The results of these analyses indicated that neither the group × frequency, $F_1(4,152) = .48$, $F_2(4,420) = .30$, nor the group × consistency interactions, $F_1(8,304) = 1.93$, $F_2(8,420) = 1.60$, reached significance. However, there was a reliable group × frequency × O–P correspondence interaction, $F_1(8,304) = 2.78$, $p < .01$, $F_2(8,420) = 1.96$, $p = .049$. As in the overall analyses of error rates (see Fig. 3), this interaction reflected the fact that there were more outliers for the healthy young adults in the unique low-frequency condition than the remaining conditions, whereas, for the remaining groups of subjects the outliers were more equally represented across conditions. This pattern clearly indicates that the lack of an increasing O–P correspondence effect or the lack of an increasing frequency by O–P correspondence interaction across our subject groups in the response latency data is not simply due to relatively more trimming of *slow* responses in the unique low-frequency condition in our more severely impaired subjects. If anything, there was some tendency for just the opposite to occur.

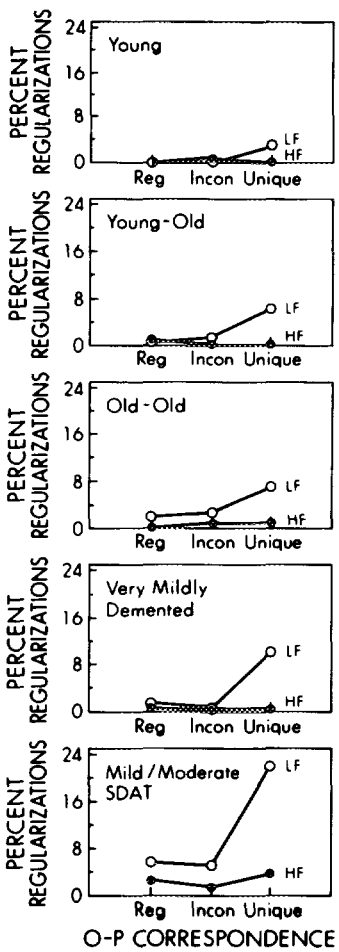

FIG. 4. Mean percentage regularizations as a function of group, word frequency, and O–P correspondence.

tributed to a number of reliable effects in the ANOVA. First, overall there was an increasing number of regularizations across groups of subjects, $F_1(4,152) = 12.71$, $p < .001$, $F_2(4,420) = 23.02$, $p < .001$. Second, low-frequency words overall produced more regularizations than high-frequency words, $F_1(1,152) = 92.24$, $p < .001$, $F_2(1,420) = 66.69$, $p < .001$. Third, there was a reliable effect of O–P correspondence on regularization errors, $F_1(2,304) = 77.46$, $< .001$, $F_2(2,420) = 34.63$, $p < .001$. Fourth, the influence of O–P correspondence is greater for low-frequency words than high-frequency words, $F_1(2,304) = 73.18$, $p < .001$, $F_2(2,420) = 31.15$, $p < .001$. Fifth, the influence of Frequency increased across groups, $F_1(4,152) = 11.23$, $p < .001$, $F_2(4,420) = 8.28$, $p < .001$. Sixth, the influence of O–P correspondence increased across groups, $F_1(8,304) = 9.58$, $p < .001$, $F_2(8,420) = 4.45$, $< .001$. Finally, the relatively localized increase in the regularization errors for the low-frequency unique words yielded reliable group × frequency × O–P correspondence interactions, $F_1(8,304) = 6.14$, $p < .001$, $F_2(8,420) = 2.64$, $p = .008$.

General Discussion

The results of the present study are straightforward. First, the present study replicated the frequency × O–P correspondence interaction reported by Seidenberg et al. (1984), among many others. Specifically, low-frequency words produced a larger influence of O–P correspondence than high-frequency words in each of five groups of subjects that varied substantially in overall naming latency. In fact, from the young to the mild/moderately demented individuals there was a twofold increase in overall response latency. Second, the present results provided evidence that the frequency effect systematically increased across our subject groups. Specifically, there was a threefold increase in the frequency effect going from the young adults to the mild/moderately demented individuals. Third, although there was a substantial increase in the frequency effect, there was no evidence of an increase in the O–P correspondence effect across subject groups. Finally, there was a systematic increase in the regularization errors across the subject groups that was primarily localized in the low-frequency unique words. Before discussing the theoretical implications of these results, we shall first discuss some possible interpretive constraints regarding the present data.

Possible Interpretive Constraints

There are three possible interpretive constraints that should be noted. First, when one only considers the regular and incon-

sistent items, there is no evidence in the present data for a frequency by consistency interaction. These results appear inconsistent with the results of Seidenberg et al. (1984) who reported that for the low-frequency stimuli there was a large difference between regular and inconsistent words (30 ms), whereas for high-frequency words there was no difference (actually, −5 ms). Interestingly, Jared, McRae, and Seidenberg (1990) have recently reported an attempted replication with the same materials and found considerably reduced consistency effects (9 ms) for the low-frequency words (the high-frequency words were not included). Based on a comparison of overall response latencies across the two studies, and the fact that Seidenberg (1985) has found larger consistency effects in less-skilled readers, Jared et al. attributed this failure to replicate to the notion that subjects in the original Seidenberg et al. study were less skilled than in the Jared et al. replication. However, this does not appear to account for the lack of interaction in the present study because if one uses overall response latency as an indicant of word recognition skill (as Jared et al. did), the present results provide little evidence for a frequency by consistency interaction across five different levels of reading skill. Because of the considerable power in the present study (157 subjects), compared to the Seidenberg et al. study (15 subjects), along with the apparent failure to replicate the original Seidenberg et al. pattern in the Jared et al. study, we believe that it is likely that this particular set of words will not consistently produce the frequency by consistency interaction. However, based on Jared et al.'s review of the literature, we also believe that the consistency by frequency interaction can be reliably obtained and that the presence of such interactions are dependent upon the frequency of similarly spelled friends (words with similar O–P correspondences) and the frequency of similarly spelled enemies (words with different O–P correspondences). As Jared et al. point out, the low-frequency set of stimuli in question includes words with both high-frequency friends and high-frequency enemies.

The second potential interpretive constraint involves the possibility that the increasing frequency effect across the subject groups could reflect a type of scaling problem. Specifically, one might argue that because the younger adults produce response latencies that are considerably faster than the mild/moderately demented individuals, the smaller influence of frequency in the younger adults is simply due to the fact that younger adults are at a different point on the response latency scale and hence all effect sizes will be diminished. Although this is always a potential problem when one compares effect sizes under conditions where there are large group differences in overall response latency, there is an important aspect of the present data that diminish the strength of this argument. Specifically, if one considers the data in Fig. 2, one can see that the sizes of the frequency effect and the uniqueness effect are identical for the young adults. However, across groups the frequency effect increases threefold whereas there is absolutely no increase in the uniqueness effect. Hence, even if there are potential scaling problems, these data clearly indicate that the influence of uniqueness and frequency can be dissociated across the subject groups.

The third potential interpretive constraint is that it is possible that the increase in frequency effects across the subject groups is not due to the influence of frequency on lexical access processes, but rather, may be due to the influence of frequency on processes involved in pronouncing the word aloud after it has been recognized. For example, Balota and Chumbley (1985) have provided evidence that part of the frequency effect can occur in processes that may be involved in pronouncing the word aloud after it has been recognized. Although there has been some controversy regarding the amount of contribution of postlexical processes to the frequency effect in speeded naming performance (e.g.,

Balota & Chumbley, 1989; Connine, Mullennix, Shernoff, & Yelen, 1990; McRae, Jared, & Seidenberg, 1990; Monsell, Doyle, & Haggard, 1989; Savage, Bradley, & Forster, 1990), it is quite possible that some component of the increasing frequency effect across our subject groups may be due to an increasing postaccess influence of frequency.

Recently, Balota and Ferraro (1993) attempted to address the possibility that there are age-related changes in the contribution of postlexical influences of frequency in the naming task. In this study, healthy young and older adults participated in a delayed naming task in which on critical trials a 150-ms auditory tone was presented 1200 ms after the onset of the to-be-pronounced target word. The notion is that after a 1200-ms delay, it is unlikely that any remaining frequency effect is unequivocally due to the influence of frequency on processes involved in recognition of the target. The results indicated that there were reliable and virtually identical frequency effects for the young (11 ms) and older adults (10 ms) in this delayed naming condition. Thus, there appears to be little change in the influence of frequency on postlexical processes at least between healthy young and older adults. Unfortunately, we were unable to run a similar study with SDAT individuals because these individuals have difficulty withholding (inhibiting) the response to await the response cue, i.e., they are likely to name the stimulus word before the response cue. Thus, although it is still possibly that there is a postlexical contribution to the increasing frequency effect across our subject groups, the available evidence regarding such an influence does not provide strong support for this contention.

Theoretical Implications of the Present Results

We shall now turn to the theoretical implications of these results. As noted above, the importance of the present results is that we have identified a factor (subject group) that has different influences on the frequency effect and the O–P correspondence effect. This finding is of interest because both unembellished dual-route models and single-route models assume that both factors influence the same mechanism in the processing system. By independently influencing the frequency effect and not influencing the O–P correspondence effect, we have brought some of the fundamental assumptions within these models into question. We shall now turn to a discussion of how such a pattern might be reconciled within these models.

Single-Route Account

First, consider the single-route model of Seidenberg and McClelland (1989). Because both frequency effects and O–P correspondence effects in naming are a natural consequence of the same set of connections among orthographic units and hidden units and among hidden units and phonological output units, it is unclear how such a system might produce different effects of these factors across our subject groups. As noted in the Introduction, Seidenberg and McClelland attempted to model the breakdowns that are observed in developmental dyslexics by changing the network, via decreasing the total number of hidden units. As one might suspect, this had the effect of increasing the effect size of frequency, O–P correspondence, and apparently, the interaction between these two variables (see Seidenberg & McClelland, 1989, Fig. 21, p. 548). Thus, a decrease in the number of hidden units does not appear to be an acceptable account for the observed isolated changes in the frequency effects across the present subject groups.

Of course there are alternative ways to damage such a connectionist model, and it is possible that one of these may be able to account for the present data. For example, one might add random noise to the activation process. An interesting and potentially important aspect of the present results is that there are different effects across sub-

ject groups depending upon the dependent measure one is considering, e.g., response latency versus probability of a regularization. Possibly, instead of mapping error scores primarily onto response latency data as in the Seidenberg and McClelland model, it would be useful to look at the phonological error scores as these error scores relate to other potentially related outputs. For example, what is the error score for *pint* such that it rhymes with *hint?* Interestingly, once this step is taken the single-route model begins to take on some of the characteristics of a dual-route model. That is, performance is dependent upon the relation between the phonological error scores for the correct lexical output (addressed route) and the phonological error scores for potential regularizations (assembled route). The fact that O–P correspondence has different effects on response latency and regularization errors across our subject groups suggests that an analysis of the phonological error scores of incorrect potential regularizations may provide further insight into how the model settles upon an actual output. It appears that on some trials the incorrect regularization is strong enough to be selected without a cost in response latency. As discussed below, it is precisely this selection process that may break down across the present subject groups.

Dual-Route Account

Now, consider the dual-route model. As noted in the Introduction, the dual-route model accounts for the frequency by O–P correspondence interaction by suggesting that the addressed route for high-frequency words operates too fast to be influenced by the slower assembled route. However, the addressed route for low-frequency words is relatively slower than for high-frequency words, and therefore, there is sufficient time for output from the assembled route to arrive at a common computational stage to influence performance. The present study indicates that one can strongly modulate the speed of the addressed route across subjects, as reflected by the group by frequency interaction, but this does not appear to influence the likelihood of the assembled route influencing output. In fact, one could argue that we have slowed the addressed route three times more in our mild/moderately demented individuals compared to our healthy young individuals (i.e., there was a threefold increase in the frequency effect); however, there is no evidence that there is an increase in the influence of the assembled route. This is inconsistent with the basic premise of dual-route models that asserts the speed of the addressed route predicts the likelihood of competition from the assembled route.

There are, at least, two major attacks a dual-route theorist might take to account for the present pattern of data. The first attack is that there is simply a decreased influence of the assembled route across our subject groups that compensates for the expected increased O–P correspondence effect. If there were a decreased influence of the assembled route across the subject groups then it is possible that there would be an increasing frequency effect, but not an accompanying increasing O–P correspondence effect. The second attack is that there is a breakdown in inhibitory processes across our subject groups. We will now discuss each of these hypotheses in turn.

Group-related decreased influence of the assembled route. One reason why we may not have observed an increased O–P correspondence effect, in conjunction with the observed increasing frequency effect, is because of the assumed increased attentional demands of the assembled route. As noted in the Introduction, there is recent evidence suggesting that the assembled route demands more attentional capacity than the addressed route (Paap & Noel, 1991). If this were the case and if there were increased attentional capacity breakdowns across our subject groups, as Graf, Tuokko, and Gallie (1990), Hasher and Zacks (1979), Jorm

(1986), and Plude and Hoyer (1985) have argued, then one might expect a decreased influence of the assembled route across our subject groups. Of course, one must then ask why one finds the increasing influence of word frequency across groups? This could be explained by a breakdown in the addressed lexically mediated route. In fact, Balota and Duchek (1988) reported evidence that supports the contention that there is indeed some breakdown in lexical access processes in healthy older adults compared to healthy young adults. Such a breakdown could account for the increased word frequency effect. Of course, in order for this approach to account for the present data, one would also have to argue that the breakdown in the assembled route is greater than the breakdown in the addressed route.

Thus, one way in which the dual-route model could account for the present data relies on the assumption that the direct access route is degraded, thereby producing larger frequency effects, and at the same time the assembled route is also disrupted but relatively more than the direct access route. Although a decreased influence of the assembled route along with a degraded access process would appear to account for the present data, there is a rather glaring problem with this account. Specifically, it is unclear why there is an *increasing* number of regularization errors across our subject groups. It appears that at the level of regularization errors the assembled route is actually having more of an influence on naming performance across our subject groups. Hence, even though there appears to be a plausible reason (attentional changes) to expect a decreased influence of the assembled route across the subject groups in the response latency data, this argument is inconsistent with other important aspects of the present data.

Failure to inhibit the incorrect assembled route. As noted earlier, it is possible that changes in the ability to inhibit partially activated (assembled) but incorrect information for exception words may have lead to the obtained pattern. Before turning to the details of this account, it is necessary to briefly review the evidence that there are indeed age-related and SDAT-related breakdowns in inhibitory processing.

First, regarding age-related changes in inhibitory processing, consider the results of a recent study by Hasher et al. (1991). In this study, subjects simply named which of two letters flanking either side of fixation was presented in a designated color, e.g., *red*. On trial n, subjects might be presented with a *green B* and a *red E*, and required to respond "*E*". On trial $n + 1$, the pair may now be a *red B* and a *green C*. Note, that the target letter *B* on trial $n + 1$ was actually the ignored letter on trial n. Hasher et al. found that for young adults there was reliable inhibition for such trials compared to trials in which there were no such cross-trial relationships (e.g., on trial $n + 1$, a *red D* and a *green C* might be presented). More importantly, older adults failed to produce such inhibition. Hasher et al. viewed these data as suggesting that older adults have a general breakdown in inhibitory processing. Interestingly, this same pattern has been recently reported by McDowd and Oseas-Kreger (1991) and Tipper (1990). In fact, Hasher and Zacks (1988) have recently developed a theoretical framework that emphasizes a breakdown in the inhibition of irrelevant information to account for the rather widespread breakdowns in cognitive performance in healthy aged individuals compared to healthy young individuals.

Balota and Duchek (1991) have extended the notion of a breakdown in inhibitory processes to SDAT individuals. In the Balota and Duchek study healthy older adults and SDAT individuals were sequentially presented three words on each trial. For the present purposes, we will focus on the concordant condition (e.g., *music–organ–piano*), the discordant condition (e.g., *heart–organ–piano*), and the unrelated condition (e.g., *heart–ceiling–piano*). The ma-

jor dependent variable was the speed to name the third word (e.g., *piano*) in each triad. The results indicated that healthy aged individuals produced equivalent performance on the discordant and the unrelated condition, both of which were reliably slower than the concordant condition. These data were viewed as suggesting that for the healthy aged individuals, the context word (e.g., *heart*) selected the meaning of the ambiguous word (e.g., *organ*) and inhibited the activation for the unrelated meaning (referring to *musical instrument*) such that it was no longer available to facilitate the naming of the related target word (e.g., *piano*). More importantly, however, when one considers the SDAT individuals, they were reliably faster to name the discordant target word (*piano* when preceded by *heart* and *organ*) compared to the unrelated target word (*piano* when preceded by *heart* and *ceiling*). Balota and Duchek interpreted this pattern to indicate that SDAT individuals failed to use the context word to inhibit the irrelevant meaning of the homograph in the discordant condition.

The results of these studies appear to suggest that there is an increasing failure to inhibit partially activated but incorrect information across young and older adults and across older adults and SDAT individuals. This is quite intriguing with respect to the present results. It is possible that although there is an increasing frequency effect across our subject groups in response latency there is not an increasing influence of O–P correspondence because there is a general breakdown in the inhibition of the output from the assembled route.

Consider the task facing the subject when both routes are activated and there is inconsistent output from these routes. The subject must in some sense inhibit the output from the assembled route for the exception words. It is possible that the SDAT individuals, and to a lesser degree the healthy aged individuals have a breakdown in the inhibition of the output from the assembled route. If this were the case then one would expect more regularization errors across our subject groups, precisely as we found in the present data. Specifically, instead of inhibiting the assembled route, and resolving the conflict between the two activated routes, which would produce a slowdown in response latency, the healthy older adults, and to a greater extent the SDAT individuals, are more likely to simply output the assembled route on some percentage of trials. Thus, we are suggesting that across our subject groups there is an increasing likelihood of accepting the assembled route in conflicting situations, instead of expending the energy needed to inhibit the output from the assembled route. Of course, one would still need to appeal to some breakdown in the direct access route to produce the increasing frequency effect across subject groups. Moreover, one would also need to argue that the breakdown in the inhibition of the assembled route compensates for the breakdown in the direct access route. However, given these two assumptions, the present data can be viewed as consistent with both a dual route model of naming performance and also recent evidence to suggest that there are breakdowns in inhibitory processes in both healthy older adults and in SDAT individuals.

A Few Remaining Issues

Finally, there are three remaining issues that are noteworthy with respect to the present data. First, these data do not simply follow the powerful general slowing principle of information processing across young, healthy aged individuals, and SDAT individuals. That is, according to a general slowing model (e.g., Birren, 1974; Cerella, 1985; Myerson, et al., 1990; Nebes & Brady, 1992; Salthouse, 1985), all information processing stages are slowed by a rate that is proportional to overall response latency. Thus, all effect sizes should be larger as one finds increases in response latency across groups in a given task. Although this

model handles a considerable amount of the data in the cognitive aging and Alzheimer's disease literature, this model does not adequately account for data where one variable (e.g., word frequency) produces an age-related or dementia related increase across subject groups, whereas, a second variable (O–P correspondence) fails to produce such an increase. In this light, the general slowing approach is a good heuristic against which to isolate cognitive operations that change at a different rate across age and dementia levels. Frequency effects appear to conform to a general slowing approach but clearly O–P correspondence effects do not, at least in pronunciation latency.

A second issue that needs to be noted here is that there is a reliable increase in the frequency effect across our three groups of healthy adults. Allen, Madden, and Crozier (1991) have recently argued that at least in lexical decision performance, word frequency is additive with age in healthy young and older adults. The present results indicate that there is an increasing frequency effect in naming performance across healthy young, young–old, and old–old subject groups. It is interesting to note here that although Allen et al. argued that age and frequency produced additive effects in their lexical decision task, there was actually a 51-ms increase in the difference between the very low-frequency words and the very high-frequency words across their young and older adults. Thus, although it is possible that differences between the naming task and the lexical decision task may have produced the difference across the present study and the Allen et al. study, it is also possible that the Allen et al. study reflects a failure to reject the null hypotheses.

Finally, the increasing frequency effect across our age groups is particularly important in light of recent arguments regarding increasing semantic priming effects across young and older adults. Myerson, Ferraro, Hale and Lima, (1992) and Laver and Burke (1993) have both recently reported evidence from metaanalytic studies that indicate that across studies of semantic priming, healthy aged individuals produce larger semantic priming effects than healthy young adults. It is possible that because there is clear evidence that semantic priming effects are larger for low-frequency words than for high-frequency words (Becker, 1979), the increase in the semantic priming effect may in part reflect the increasing frequency effect across subject groups.

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