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Visual Word Recognition Across the Adult Lifespan

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The current study examines visual word recognition in a large sample ($N = 148$) across the adult life span and across a large set of stimuli ($N = 1{,}187$) in three different lexical processing tasks (pronunciation, lexical decision, and animacy judgment). Although the focus of the present study is on the influence of word frequency, a diverse set of other variables are examined as the word recognition system ages and acquires more experience with language. Computational models and conceptual theories of visual word recognition and aging make differing predictions for age-related changes in the system. However, these have been difficult to assess because prior studies have produced inconsistent results, possibly because of sample differences, analytic procedures, and/or task-specific processes. The current study confronts these potential differences by using 3 different tasks, treating age and word variables as continuous, and exploring the influence of individual differences such as vocabulary, vision, and working memory. The primary finding is remarkable stability in the influence of a diverse set of variables on visual word recognition across the adult age spectrum. This pattern is discussed in reference to previous inconsistent findings in the literature and implications for current models of visual word recognition.

Keywords: word frequency, visual word recognition, cognitive aging

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Language is perhaps the most critical of higher level cognitive skills. Although older adults often display deficits in many higher order abilities, such as memory (e.g., Craik, 1994), attention (e.g., Craik & Byrd, 1982; Hasher & Zacks, 1988; Madden, 2007), and decision making (e.g., Boyle et al., 2012), there is less prominent age-related decline in language performance, with older adults often outperforming young adults (e.g., Verhaeghen & Salthouse, 1997).

The goal of the current project is to examine how one component of language processing, visual word recognition, changes across the adult age spectrum. There has been considerable work on visual word recognition focused on younger adults and in cross-sectional studies of young and older adults. However, there have been varying degrees of attention in this literature to age-related variables that might influence word recognition performance, such as increased exposure to language across the age spectrum and age-related declines in component processes, including processing speed, sensory processing, and attention. There is now accumulating evidence that individual differences in language processing can influence basic visual word recognition, manifested as changes in the influence of standard lexical variables. For example, compared with individuals with relatively low vocabulary, young adults with high vocabulary show evidence of more accurate and efficient lexical processing, as indexed by a smaller influence of standard predictor variables on word recognition performance (e.g., neighborhood structure, word frequency, semantics; see, e.g., Yap, Balota, Sibley, & Ratcliff, 2012). The natural extension of this individual-differences work is to older adults, who have more experience than younger adults with language (more encounters with each word in different contexts), which is often reflected in higher vocabulary knowledge (see Verhaeghen, 2003). In fact, there is some evidence that older adults who have been exposed to a relatively large amount of text (as measured by a "print exposure test") show smaller word frequency effects than those with less exposure to text (Payne, Gao, Noh, Anderson, & Stine-Morrow, 2012).

In contrast to the potential benefits of increased language exposure as one ages, there are a number of well-documented domains that show age-related breakdowns, including processing speed (Salthouse, 1996), lower level sensory abilities (Fozard & Gordon-Salant, 2001), and attentional control (Kramer & Kray, 2006). Processing speed differences are a notorious confound in aging research, particularly when response times (RTs) are the dependent variable of interest. Indeed, processing speed often accounts for most age-related variance in cognitive tasks (e.g., Salthouse, 1994, 1996). Similarly, vision is critical to visual word recognition tasks but also declines with increasing age (Schieber, 2006). A potential consequence of this sensory decline is that incoming visual information appears partially degraded, even for vision-corrected participants, and therefore may require additional processing to decode. Indeed, declines in sensory uptake have been shown to

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impede additional higher level processing such as comprehension and memory (Cronin-Golomb, Gilmore, Neargarder, Morrison, & Laudate, 2007; McCoy et al., 2005; Tun, McCoy, & Wingfield, 2009; Wingfield, Tun, & McCoy, 2005). Aging is also associated with declining attentional control and working memory, abilities also thought to be important for even lower level language processing tasks (Hasher & Zacks, 1988; Salthouse & Babcock, 1991). Hence, a major goal of the present project is to assess the contributions of age-related changes in processing speed, vision, and working memory to visual word recognition performance.

In addition to considering visual word recognition across the adult age spectrum (while examining potential mediating variables), it is important to consider the contribution of such a study to current models of visual word recognition. Interestingly, there are clear differences in the predictions from the major models of visual word recognition regarding the influence of experience and age, and so examining visual word recognition across the adult age spectrum affords a unique opportunity for adjudicating amongst the relevant models. The clearest distinction across the models is with respect to the influence of age on the effects of the most-studied variable in visual word recognition: word frequency. Word frequency is a metric of how often a word is encountered in the language, and is the most robust predictor of performance across a range of experimental tasks. Because of this, all models and theories of visual word recognition account for the *word frequency effect*: faster and more accurate responding to higher frequency words relative to lower frequency words.[1]

The differing predictions across models regarding the influence of age on the word frequency effect reflect distinct mechanisms that each model uses to accommodate the word frequency effect. One account (Samuels, LaBerge, & Bremer, 1978; Spieler & Balota, 2000) posits increased holistic processing of word representations across the life span because of increased exposure to words. If frequency is tied to the full lexical form, under this account, one might expect older adults to produce larger word frequency effects than younger adults. On the other hand, a logogen-type account (see Morton, 1969), in which individual word thresholds benefit from experience garnered over the lifetime, may actually predict a decreased word frequency effect in older adults because as one ages, the lexical representations approach asymptotic levels (as described in Murray & Forster, 2004). According to this perspective, older adults might produce smaller word frequency effects because lower frequency words may move into the middle-frequency range because of increased exposure across the life span. Indeed, one finds little influence of word frequency when comparing middle- to high-frequency words (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; Brysbaert et al., 2011). Finally, two models also predict constancy in the word frequency effect across age. According to the lexical rank hypothesis (see Murray & Forster, 2004), one might expect that word frequency should be additive with age, because the rank position of a word is based on its frequency of occurrence, and this rank should not change as a function of age. The transmission deficit hypothesis posits that weakened transmission of activation throughout the cognitive system is disproportionately large for infrequently accessed words relative to more frequently accessed words, but only for language production, which uses connections from one node to many (Burke & MacKay, 1997; Burke & Shafto, 2008; MacKay, Abrams, & Pedroza, 1999). On the other hand, the type of language perception required in the current study uses many-to-one connections, which are assumed to remain intact with age, thus predicting no relationship between age and the word frequency effect. In sum, across these distinct theoretical perspectives, one predicts decreasing, increasing, or no effect of age on the word frequency effect. The current study affords an opportunity to discriminate among these alternatives while controlling for additional critical variables that have been shown to influence visual word recognition.

Although examining age-related changes in the word frequency effect is a compelling test-bed for models, there has been remarkable inconsistency in the single-word production or recognition literature regarding this relationship. Table 1 provides a description of the results from these studies. As shown, five studies have provided evidence for increased word frequency effects with age, six studies have provided evidence for no difference in word frequency effects as a function of age, and two studies have provided evidence for decreasing word frequency effects with age. Of course, here, we are focusing on word frequency effects, but it is noteworthy that each of these studies also addressed additional variables. We believe the inconsistency in word frequency effects is likely because of one or more of the following reasons across studies: (a) inconsistency in controlling for age-related changes in processing speed, vocabulary, and/or attention; (b) inconsistency in controlling for well-known additional lexical variables (e.g., word length, orthographic neighborhood structure, spelling to sound consistency, concreteness, emotional valence) that could contribute to the influence of word frequency; (c) the use of extreme groups designs as opposed to continuous measures of both age and lexical variables; and (d) variations in tasks that emphasize different aspects of lexical processing.

The present study will attempt to address these issues in the following manner. First, as Grainger and Jacobs (1996) argue, it is critical to triangulate across lexical processing tasks in order to generalize beyond task-specific processes to isolate task independent characteristics of lexical processing (see also Balota & Chumbley, 1984, 1985). Hence, in the present study, we use, arguably, the three most widely used tasks of visual word recognition: lexical decision, pronunciation, and semantic classification (in this case, animacy judgment). Each task places different emphases on aspects of lexical processing, with lexical decision being driven by decision processes used for discriminating words from nonwords, pronunciation being driven by spelling to sound conversion, and animacy judgment being driven by decision processes that emphasize semantics. These tasks also often produce differences in the magnitude of the word frequency effect—for example, the lexical decision task produces larger word frequency effects than the pronunciation task (see Balota & Chumbley, 1984, 1985). Second, we use a regression approach, which allows us to examine a continuous set of well-established predictor variables to examine the unique effect of word frequency above and beyond these correlated variables (see Balota et al., 2004). Third, we examine these issues across a large set of individuals ($N = 148$) and items

[1] Although the "word frequency effect" has historically been used to denote a difference in performance between low- and high-frequency words, in the current study, it is used for the continuous influence of word frequency, as in reliable regression coefficients.

Table 1
Summary of Prior Studies on the Age × Word Frequency Interaction

Primary finding	Study	Task	Participant variables	Word frequency metric
Age constancy	Bowles & Poon (1985)	Lexical decision	Vocab	Kuĉera & Francis (1967)
	Tainturier et al. (1989)	Lexical decision	Education	Juilland et al. (1970)
	Allen et al. (1991)	Lexical decision	Education, speed, vocab	Kuĉera & Francis (1967)
	Allen et al. (1993)	Lexical decision	Education, speed, vocab	Kuĉera & Francis (1967)
	Whiting et al. (2003)	Lexical decision	Vocab	Carroll et al. (1971)
	Allen et al. (2011)	Pronunciation	Education, speed, vocab	Carroll et al. (1971); Kuĉera & Francis (1967)
Word frequency effect increases with age	Balota & Ferraro (1993)	Pronunciation	Psychometrics	Carroll et al. (1971)
	Balota & Ferraro (1996)	Lexical decision	Vocab, psychometrics	Kuĉera & Francis (1967)
	Spieler & Balota (2000)	Pronunciation	Education, vocab	Francis & Kuĉera (1982)
	Ratcliff, Thapar, Gomez, & McKoon (2004)	Lexical decision	Education	Kuĉera & Francis (1967)
	Balota et al. (2004)	Pronunciation	Education, vocab	Multiple
Word frequency effect decreases with age	Morrison, Hirsh, Chappell, & Ellis (2002), Exp. 1b	Pronunciation	Vocab	Baayen, Piepenbrock, & Gulikers (1995)
	Balota et al. (2004)	Lexical decision	Education, vocab	Multiple

Note. Exp. = experiment; Vocab = vocabulary; RT = response time; WF = word frequency.

(N = 1,200), which allows for both age and the lexical variables to be continuous predictors while avoiding potential problems with extreme items and/or groups designs (see Salthouse, 2000). Fourth, we consider individual difference measures of processing speed, vocabulary, sensory ability, and working memory to determine the extent to which age-related changes in these participant characteristics may modulate the observed patterns.

Method

Participants

A total of 148 participants, ranging in age from 18 to 86 years (M = 47.0), were included in the data analysis. All participants were recruited through the Washington University Research Participant Registry and paid $10 an hour for approximately two hours of participation. This registry contains over 15,000 potential study participants of all ages, including over 27% of minority status. Importantly, a diverse sample such as this is not typical of standard aging studies using extreme groups (in which the older adults in the sample are often more highly educated than the younger adult samples; further discussion to follow), but affords a more representative sample of the population across the adult spectrum. Overall and age-group specific participant characteristics are presented in Table 2. An additional six participants completed the study but were eliminated for (a) difficulty in following task instructions (n = 3), (b) being a non-native English speaker (n = 1), (c) having less than 70% accuracy on animacy judgment (n = 1), or (d) having less than 80% accuracy on pronunciation (n = 1).

Stimuli

A total of 1,200 words were selected for use in this study. These stimuli were taken from multiple sources. First, 493 words were taken from Andrews and Heathcote (2001), which were nouns divided equally into nonliving and living, and high and low frequency. An additional 975 words were selected from the monomorphemic nouns (N = 4,842) in the SUBTLEX database (Brysbaert & New, 2009).

In order to ensure that the items produced consistent animacy judgments across participants for the animacy judgment task, a norming study was conducted on Amazon's Mechanical Turk (MTurk; mturk.amazon.com). One hundred fifty-seven participants[2] rated animacy of words as "definitely non-living," "mostly non-living," "ambiguous," "mostly living," "definitely living," or "do not know." Participants rated an average of 220 words each, although participants who did not complete the task but rated at least 100 words were included. This norming procedure resulted in at least 15 participant ratings for each of 1,468 words. The 600 living and 600 nonliving words with the highest concordance scores (the number of people who rated the word as "definitely" or "mostly" living or nonliving, divided by the total number of ratings for that word) were selected for use in the current study. The animate and inanimate words ranges were .67 to 1.00 and .79 to 1.00, respectively, with similar means (.90 for animate; .94 for inanimate) and standard errors (.004 for animate; .003 for inanimate). Table 3 provides characteristics of the full stimulus set, and Table 4 provides correlations among the item predictor variables and task performance.

Three counterbalancing lists were created using a random number generator to rotate through the three different tasks, with the caveat that each list required 200 animate and 200 inanimate words. A one-way ANOVA indicated that the lists did not differ significantly on concordance, length, raw or LOG HAL or SUBTLEX word frequency, orthographic or phonological N, orthographic Levenshtein distance (OLD) or phonological Levenshtein

[2] All participants were from the United States and reported fluency in English. These participants were 49.4% female and had a mean age of 37.8 years (SD = 11.5, range = 20–68) and reported a range of highest-education-level categories (n = 1 for some high school; n = 25 for high school graduate; n = 43 for some college, no degree; n = 16 for associates degree; n = 62 for bachelor's degree; and n = 10 for graduate degree). The wide ranges of age and education are comparable with the participants tested in the current study.

Table 2
Participant Characteristics, Overall (Top) and Split by Age Group (Bottom)

Predictor	Mean	Standard deviation	Minimum	Maximum
Age	47.01	19.65	19.00	86.00
Short Blessed score	.82	1.38	.00	8.00
Vision factor	.00	1.00	–4.04	1.86
Education in years	15.64	2.45	9.00	22.00
OSpan	31.40	6.73	15.00	45.00
Shipley vocabulary	32.68	4.32	18.00	39.00
Reading/week in hours	16.42	16.45	.00	84.00

	Younger adults (Ages 18–30, $n = 46$)	Middle-aged adults (Ages 31–59, $n = 51$)	Older adults (Ages 60+, $n = 51$)
Age	24.0	45.86	69.39
Short Blessed score	.60	1.00	.90
Vision factor	.70	.17	–.81
Education	15.8	15.15	15.99
OSpan	33.9	31.14	29.17
Shipley vocabulary	30.9	31.74	35.20
Reading/week in hours	15.7	18.52	15.12

Note. OSpan = operation span, reading/week stands for self-reported hours read per week.

distance (see Yarkoni, Balota, & Yap, 2008), number of syllables, or number of morphemes ($ps > .05$), taken from the English Lexicon Database (Balota et al., 2007). Approximately equal numbers of participants across the life span completed the different counterbalance lists.

Nonword stimuli ($N = 400$) for the lexical decision task were generated by the Nonword Generator Wuggy (Keuleers & Brysbaert, 2010), which segmented the 1,200 word stimuli into syllables and recombined them to create 400 nonwords. All participants saw the same 400 nonwords, which were equated with the word stimuli on length in letters, $t(1,583) = .52$, $p = .603$. As expected, words and nonwords differed on orthographic N, $t(1,583) = 3.51$, $p < .001$. Table 3 provides the item characteristics, Table 4 provides the correlation matrix, and the online supplemental materials provide the word and nonword stimuli.

Procedure

Participants completed the visual word recognition tasks and several other tasks in a single 2-hr experimental session in the following order: the dementia screening measure Short Blessed Test (Katzman et al., 1983), animacy judgment, 10-ft. and computer distance vision tests (combined into a single standardized vision factor score for analyses), word pronunciation, Shipley vocabulary (Shipley, 1946), lexical decision, and operation span (OSpan; based on Engle, Tuholski, Laughlin, & Conway, 1999). The emphasis in this study is on individual differences, so order was kept constant to eliminate variability across participants because of counterbalancing order. Within each word recognition task, participants completed 12 practice trials in each task, followed by 400 trials in the animacy judgment and pronunciation tasks and 800 trials in the lexical decision task. As noted, stimuli were rotated through the tasks within three counterbalanced lists so that each participant saw each word only once across all tasks, and words were presented equally across lists and tasks.

On each trial in each of the visual word recognition tasks, participants first saw a 400-ms fixation cross at the center of the screen to indicate that the trial was about to begin. The stimulus then appeared and participants were instructed to provide the appropriate response (reading the word aloud for the pronunciation task, pressing a key corresponding to a “word” or “nonword” decision for the lexical decision task, or pressing a key corresponding to a “living” or “nonliving” decision for the animacy judgment

Table 3
Overall Stimuli Characteristics

Item predictor variable	Mean	Standard deviation	Minimum	Maximum
Length in letters	6.05	1.74	2.00	13.00
Log SUBTLEX word frequency	2.31	.77	.30	4.97
Number of syllables	1.90	.80	1.00	5.00
Orthographic N	3.63	5.50	.00	34.00
Phonological N	8.72	12.08	.00	60.00
Orthographic Levenshtein distance	2.28	.81	1.00	6.75
Phonological Levenshtein distance	2.12	.92	1.00	6.65
Concordance	.92	.08	.67	1.00
Consistency	.63	.29	.00	1.00
Valence	5.25	1.18	1.63	8.05
Concreteness	4.23	.77	1.52	5.00

Table 4
Correlation Matrix for Item Predictor Variables and Overall Task Performance

Measure	2	3	4	5	6	7	8	9	10	11	12	13
1. Length	$-.321^{***}$	$.879^{***}$	.016	$-.445^{***}$	.003	$-.088^{**}$	$.230^{***}$	$.453^{***}$	$.594^{***}$	−.033	$-.072^{*}$	$-.209^{***}$
2. Word frequency		$-.405^{***}$	$.200^{***}$	$.132^{***}$	$.215^{***}$	.035	$-.532^{***}$	$-.693^{***}$	$-.594^{***}$	$.272^{***}$	$.492^{***}$	$.325^{***}$
3. OLD			$-.065^{*}$	$-.398^{***}$	.006	−.043	$.268^{***}$	$.497^{***}$	$.653^{***}$	$-.103^{***}$	$-.165^{***}$	$-.241^{***}$
4. Concordance				$-.061^{*}$	$.107^{***}$	$.269^{***}$	$-.446^{***}$	$-.212^{***}$	$-.186^{***}$	$.592^{***}$	$.265^{***}$	$.173^{***}$
5. Consistency					−.027	.036	−.038	$-.211^{***}$	$-.322^{***}$	−.032	.012	$.149^{***}$
6. Valence						$.147^{***}$	$-.220^{***}$	$-.214^{***}$	$-.124^{***}$	$.076^{*}$	$.133^{***}$	$.053^{+}$
7. Concreteness							$-.204^{***}$	$-.211^{***}$	$-.184^{***}$	−.0005	$.117^{***}$	$.179^{***}$
8. AJT *z* scores								$.635^{***}$	$.550^{***}$	$-.561^{***}$	$-.524^{***}$	$-.457^{***}$
9. LDT *z* scores									$.799^{***}$	$-.242^{***}$	$-.678^{***}$	$-.512^{***}$
10. PRN *z* scores										$-.223^{***}$	$-.506^{***}$	$-.545^{***}$
11. AJT accuracy											$.278^{***}$	$.184^{***}$
12. LDT accuracy												$.451^{***}$
13. PRN accuracy												

Note. OLD = Orthographic Levenshtein distance; AJT = animacy judgment task; LDT = lexical decision task; PRN = pronunciation task.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

task). The stimulus remained on the screen until a vocal (microphone) or key press response was detected, at which point, a blank screen appeared for 200 ms for the animacy judgment and lexical decision tasks, or until the experimenter coded the vocal response for the pronunciation task. This timing is comparable with the English Lexicon Project (Balota et al., 2004) lexical decision and pronunciation task events.

Results

Table 5 shows overall task performance. In order to ensure that extreme scores did not overly influence the results, we used standard outlier procedures (as in Balota et al., 2007). First, for the animacy judgment task (which produced relatively slower RTs), trials that produced response latencies below 250 ms or above 4,000 ms were removed (0.8% of trials). Trials below 250 ms and over 3,000 ms were removed for the lexical decision task (1.4% of correct trials) and the pronunciation task (1.1% of correct trials). Microphone errors (invalid triggering of the microphone on a trial; e.g., coughing or stammering) were also removed for the pronunciation task (3.2% of all trials). Correct trial RTs were then converted to *z* scores, which transforms response latency on each trial onto a standardized scale based on the mean and standard deviation of that individual participant within each task separately. This controls for the well-documented general slowing that occurs across the life span (Faust, Balota, Spieler, & Ferraro, 1999), which could compromise the results. Trials outside of three standard deviations from the mean were then removed from the remaining trials (2.2% of trials for animacy judgment, 2.2% of trials for lexical decision, and 1.6% of trials for pronunciation). Furthermore, 13 words were eliminated because mean performance across participants was less than 50% in one of the tasks (hemlock, petal, limb, bush, thigh, cell, grouse, barnacle, brasserie, cellist, dachshund, anemone, and tarot). The total percentage of trials included in the following response time (RT) analyses was therefore 91% of all observations for animacy judgment, 92% for lexical decision, and 93% for pronunciation.

RT Analyses

Two main regression approaches are reported: item level and subject level.[3] The item-level analyses, using items as the basic unit of analysis, allowed examination of the effects of the predictor variables on performance in the three tasks. These are important initial analyses to make contact with the extant literature to insure that we find the standard pattern of effects in the variables measured in the current study. The subject-level analyses involved conducting a regression analysis on each subject, using the same predictors as the item-level analyses, to obtain beta weights for each predictor variable in each task. This allows consideration of the critical questions regarding how age and correlated variables may influence the word frequency effect, along with other variables.

Regression analyses were conducted separately for each task (see Table 6). The first step of the item- and subject-level regression analyses contained a set of 13 predictors to represent phonological onsets (voicing, coded for presence/absence, voicing, bilabial, labiodental, dental, alveolar, palatal, velar, glottal, stop, fricative, affricate, nasal, and liquid; see Kessler, Treiman, & Mullennix, 2002; Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995), in order to control for onset characteristics that may affect microphone triggering in the pronunciation task. Step two contained length in letters, log SUBTLEX word frequency (Brysbaert & New, 2009; though see the "Alternative Measures of Word Frequency" section), OLD (Yarkoni et al., 2008; a measure of orthographic neighborhood), concordance (from the MTurk ratings), feedforward rime consistency taken from Yap and Balota (2009; a measure of the extent to which words which are spelled similarly are pronounced similarly), emotional valence (a scale from negative to positive; Warriner, Kuperman, & Brysbaert, 2013), and concreteness (the extent to which a word is abstract versus tied to sensory qualities, particularly vision; Brysbaert, Warriner, & Kuperman, 2014). These variables were selected based on literature suggesting they are important to one or more of the tasks in the current study (see, e.g., Yap &

[3] We also conducted linear mixed effects analyses using the LMER function in R (see Cohen-Shikora, 2015). All results were the same as the regressions reported here. Furthermore, although *z* scores are reported here, analyses of the raw RTs produced the same overall patterns as *z* scores in the item- and subject-level analyses, with the exception of a main effect of age, which is not present in *z* scores because of the *z* score correction for age-related slowing.

Table 5
Overall Performance by Task

Task	Mean Raw RT			Mean Accuracy		
	All Participants			All Participants		
Animacy judgment	944 (376)			.94 (.24)		
Lexical decision	786 (273)			.96 (.21)		
Pronunciation	572 (143)			.97 (.16)		
	Younger adults	Middle-aged adults	Older adults	Younger adults	Middle-aged adults	Older adults
Animacy judgment	876 (197)	977 (195)	980 (152)	.93 (.05)	.93 (.07)	.96 (.02)
Lexical decision	746 (136)	785 (122)	827 (116)	.94 (.05)	.95 (.07)	.98 (.02)
Pronunciation	566 (102)	574 (106)	580 (76)	.97 (.03)	.97 (.03)	.98 (.03)

Note. Standard deviations in parentheses. Younger adults ($n = 46$) are Ages 18–30; middle-aged adults ($n = 51$) are Ages 31–59; older adults ($n = 51$) are Ages 60+. RT = response time.

Balota, 2015, for a review of the word recognition literature); however, the same general results were obtained with slightly different variable selections (e.g., using a different measure of orthographic neighborhood or leaving a variable out).

Item-Level Results: Response Time in *Z* Scores

As expected, phonological onsets primarily predicted pronunciation performance, but there were also small effects of onsets for lexical decision and (marginally) animacy judgment as well (see Table 6; for brevity, phonological onset beta weights are not presented). The predictive power of onsets for pronunciation is consistent with prior studies using multisyllabic words (e.g., Yap & Balota, 2009), and tends to be less than the predictive power for monosyllabic words (e.g., Balota et al., 2004; Yap & Balota, 2009).

The second step of the item-level regression included length, word frequency, OLD, concordance, consistency, valence, and concreteness. This step predicted more variance in z scores than the first step in the animacy judgment task, as shown in Table 6. Consistent with prior literature, the influence of many of the predictor variables depended on the task.

First, word frequency effects were robust across all three tasks, but were largest for lexical decision, with animacy judgment and pronunciation producing comparable smaller effects. Large effects of word frequency in lexical decision are consistent with prior literature, because low-frequency words are more similar to nonwords, and hence produce slowed response latencies because of decision demands of the task. In this light, word frequency likely influences both the word identification stage of task performance and the decision stage of task performance (e.g., Balota & Chumbley, 1985).

Other variables showed task modulations as well. Length in letters produced a significant inhibitory effect on lexical decision and pronunciation. OLD had a significant facilitatory effect for lexical decision, and especially pronunciation; higher orthographic density was associated with faster RTs. Consistency had a facilitatory effect on pronunciation only, which was predicted on the basis of the orthography-to-phonology computation it requires (Jared, McRae, & Seidenberg, 1990).

Turning to the semantic variables, as expected, concordance was facilitatory and robust in the animacy judgment task; in fact, it was nearly as strong a predictor as word frequency. This was predicted

Table 6
Item-Level Regression Analysis Results for Z Scores and Accuracy Across Tasks

Regression step and predictors	*Z* scores			Accuracy		
	Animacy judgment β	Lexical decision β	Pronunciation β	Animacy judgment β	Lexical decision β	Pronunciationβ
Step 1: Phonological onsets						
Step 1 ΔR^2	.018	.024*	.051***	.006	.024*	.021*
Step 2:						
Length	.067	.129**	.120**	.039	.304***	.066
Word frequency	−.385***	−.512***	−.334***	.161***	.369***	.184***
OLD	.015	.150**	.360***	−.043	−.264***	−.090
Concordance	−.335***	−.024	−.039	.613***	.105***	.051
Consistency	.037	−.033	−.090***	−.008	−.002	.122***
Valence	−.095***	−.079**	−.031	−.003	.026	−.018
Concreteness	−.083**	−.164***	−.140***	−.180***	.086**	−.131***
Step 2 ΔR^2	.363***	.492***	.508***	.395***	.199***	.508***
Total R^2	.381***	.516***	.559***	.401***	.223***	.559***

Note. OLD = Orthographic Levenshtein distance.
* $p < .05$. ** $p < .01$. *** $p < .001$.

because of the direct relevance to the animacy judgment task. Valence (coded so that higher values are positive) showed small facilitatory effects in the animacy judgment and lexical decision tasks, but not in the pronunciation task. This may be reflective of a positivity bias, and is at least consistent with the notion that negatively valenced words induce automatic vigilance and hence produce some difficulty disengaging from them (Algom, Chajut, & Lev, 2004; Estes & Adelman, 2008a, 2008b). This pattern also likely reflects the greater degree of semantic activation in the animacy judgment and lexical decision tasks relative to pronunciation. Finally, concreteness produced robust facilitation in lexical decision and, to a lesser extent, pronunciation, but had a much smaller influence in animacy judgment. Regardless of the specific magnitudes of effects across tasks, the influence of concreteness is a clear demonstration of a semantic effect on visual word recognition and/or decision processes (Balota, Ferraro, & Connor, 1991; James, 1975; Whaley, 1978), and the effect of emotional valence suggests that lexical processing can also be influenced by emotional content (Augustine, Mehl, & Larsen, 2011; Warriner et al., 2013).

Item-Level Results: Accuracy

Accuracy was defined as the number of correct trials out of total trials, not including microphone errors or RT outliers, as described in the RT data screening. It is noteworthy that participants approached ceiling performance on accuracy (94% for animacy judgment, 96% for lexical decision, and 97% for pronunciation), making accuracy measures highly skewed, and hence should be interpreted with caution. The same item-level regression analyses were conducted with mean accuracy as the dependent variable (see again Table 6). The phonological onsets predicted a small, but significant, portion of the variance for the pronunciation task and for the lexical decision task as well.

The second step of the item regression predicted considerable variance across all three tasks. Although the effects of predictor variables on accuracy performance were considerably smaller than the effects on *z* scores, there were several significant effects of predictor variables on accuracy.

Word frequency was a robust predictor of accuracy across all three tasks. Like the *z* score analyses, lexical decision showed the largest facilitatory effect of word frequency, with animacy and pronunciation showing similar, more modest effects of word frequency. Length and OLD were significant and facilitatory for lexical decision only, and consistency was significantly facilitatory for pronunciation only. Turning to the semantic variables, concordance was significant and facilitatory for animacy judgment, and was the most robust predictor, greater than even word frequency in this case. It was also significant, albeit much more modest, for lexical decision. Valence was not significant for any task, and concreteness was significant and inhibitory for animacy judgment and pronunciation, but facilitatory for lexical decision.

In sum, the item-level analyses are consistent with the available word recognition literature (see Yap & Balota, 2015, for a review). To our knowledge, this is the first study of three lexical processing tasks to triangulate lexical processes in the same set of individuals. Now we turn to the more targeted question of whether these effects change as a function of age, and are modulated by subject-level variables such as vocabulary, vision, and/or working memory.

Subject-Level Analyses

As noted, item-level regressions were conducted on each participant's data in order to obtain individual-level beta weights for each variable. This allows examination of correlations between relevant betas for each variable (focusing on word frequency) for *z* scores and accuracy and the critical participant characteristics of interest (e.g., age, vocabulary, vision). Correlations between age and subject-level predictors are displayed in Table 7, and the primary results are displayed in scatterplots in Figure 1.

Z score analyses. First, simple bivariate correlations between age and the *z* score word frequency betas were nonsignificant ($ps > .10$), except for a small significant correlation between age and the pronunciation word frequency betas ($r = .178$, $p = .030$). Because this is a positive correlation, this suggests that the as one ages, the (negative) influence of word frequency becomes smaller. Correlations between age and the rest of the lexical variables are presented in Table 8, and remarkably, almost none of the variables produced consistent correlations with age, suggesting that the visual word recognition system is relatively stable across the age spectrum studied here. The only exceptions were length effects in the animacy judgment and pronunciation tasks, which went from

Table 7
Subject-Level Correlations With Word Frequency Betas

Subject-level predictors	Age	Correlations with *z* score betas			Correlations with accuracy Exp(B)		
		AJT WF	LDT WF	PRN WF	AJT WF	LDT WF	PRN WF
Age	1.00	.024	.005	.178*	.000	.099	−.123
Age quadratic	.988***	.015	−.028	.167*	.000	.101	−.102
Short Blessed Test score	.070	−.137	−.027	−.243**	.000	−.055	−.053
Vision	−.652***	.019	−.087	−.083	.000	−.096	.145
Education	.062	.281**	.075	.115	.000	.015	−.057
OSpan	−.307**	.177	.174	.215*	.133	−.129	−.083
Shipley vocabulary	.419***	.317***	.140	.450***	.000	.030	.004
Reading per week	−.010	.067	.187*	−.025	.000	−.011	−.034

Note. The quadratic age correlations were conducted with linear age partialed out. AJT = animacy judgment task; WF = word frequency; LDT = lexical decision task; PRN = pronunciation task; OSpan = operation span and reading/week stands for self-reported hours read per week.
* $p < .05$. ** $p < .01$. *** $p < .001$.

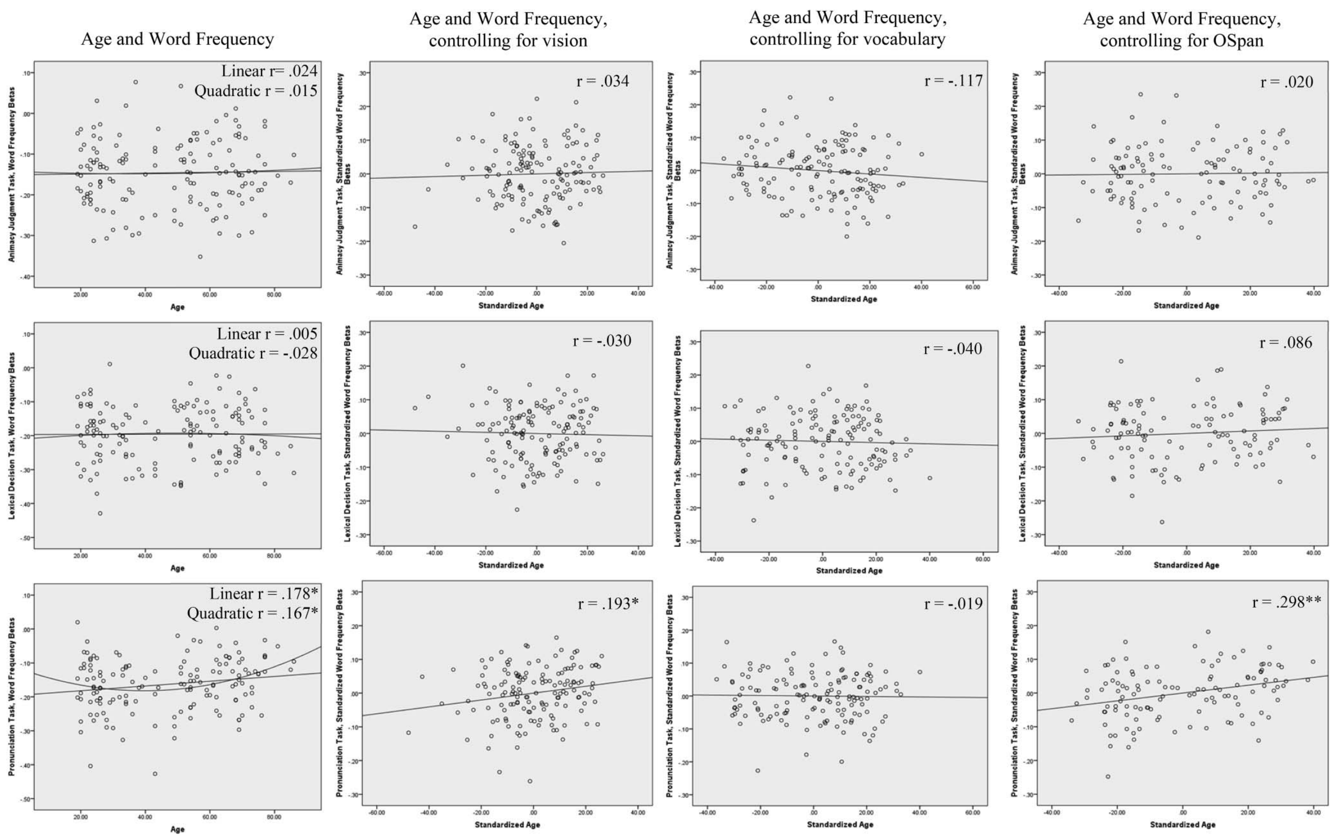

Figure 1. Scatterplots of the age/word-frequency relation. Simple scatterplots (far left) show linear and quadratic relationship between age and word frequency betas, and the other three scatterplots show the linear relationship between age (standardized) and word frequency betas, including vision, vocabulary, and OSpan as control variables. OSpan = Operation span. ** $p < .01$. *** $p < .001$.

slightly positive to slightly negative as age increased, and OLD effects, which went from close to zero to slightly positive as age increased. However, it is important to note that none of the correlations were significant at a level which would survive a *p*-value correction for multiple comparisons.

Because age was considered continuously in this study, examining the quadratic age functions are also important. Specifically, it is possible that the word-frequency effect does not change until one reaches more advanced age. Correlations between quadratic age and word frequency betas with linear age partialed out were not significant, except in the pronunciation task ($r = .167$, $p = .044$), which reflected slightly smaller word frequency effects on the extreme ends of the age spectrum (see Figure 1).

Next we examined the extent to which participant characteristics potentially modulate the relationship between age and word frequency. Previous studies differ as to which participant characteristics of younger and older adults (e.g., vocabulary) were measured and controlled for. As noted earlier, this may explain the disparate findings in prior literature if these participant characteristics are systematically associated with age and/or word frequency effects. The correlations between the participant variables and word frequency betas are displayed in Table 7. Vision and OSpan were negatively correlated with age, whereas vocabulary was positively correlated with age. These findings are consistent with prior literature (see Schieber [2006], for age differences in vision; and see Hasher & Zacks [1988] and Salthouse & Babcock [1991] for age differences in working memory), except that age and education were not correlated in the current sample and are typically positively associated in prior literature (as in a meta-analysis by Verhaeghen, 2003). This correlation in the extant literature may be because of subject pool characteristics that are not reflective of the general population, in which, if anything, greater age is associated with lower education (U.S. Census Bureau, 2014). We believe this is an advantage of the current sample.

As shown in Table 7, word frequency effects in *z* scores in the different tasks were correlated with some participant characteristics: word frequency effects in animacy judgment were correlated with the Short Blessed Test (marginally), education, and vocabulary; word frequency effects in lexical decision were correlated with vocabulary (marginally) and hours read per week; and word frequency effects in pronunciation were correlated with Short Blessed Test performance, OSpan, and vocabulary (all *p*s $< .05$ except where marginal). All correlations in *z* scores were positive (except the Short Blessed Test), indicating smaller word frequency effects with increases in the participant characteristic. This is also roughly consistent with literature suggesting that more skilled participants (indexed here by increases in OSpan, vocabulary, education, and hours read per week) have relatively more auto-

Table 8
Subject-Level Correlations Between Age and Other Variables' Effects in Z Scores

Task and variable	Correlation with age	Correlation with age, vision partialed	Correlation with age, OSpan partialed	Correlation with age, vocabulary partialed
AJT length	–.173*	–.174*	–.149	–.116
LDT length	−.001	−.011	−.012	.048
PRN length	−.184*	−.102	−.211	−.141
AJT OLD	.040	.085	−.030	.059
LDT OLD	.191*	.114	.152	.145
PRN OLD	.113	.068	.060	.098
AJT concordance	−.114	−.128	−.122	−.118
LDT concordance	−.060	−.100	−.040	−.039
PRN concordance	.057	.094	.134	.061
AJT consistency	−.129	−.101	−.069	−.128
LDT consistency	.025	−.047	.082	−.025
PRN consistency	.067	.051	.078	.101
AJT valence	.003	.074	.104	.000
LDT valence	−.032	−.141	−.066	.013
PRN valence	.067	.143	.156	.060
AJT concreteness	−.024	−.034	−.018	.006
LDT concreteness	−.041	−.022	−.059	−.033
PRN concreteness	−.119	−.107	−.188*	−.124

Note. OSpan = operation span and reading/week stands for self-reported hours read per week; AJT = animacy judgment task; LDT = lexical decision task; PRN = pronunciation task.
* $p < .05$.

matic word processing and thus are less influenced by word variables (e.g., LaBerge & Samuels, 1974; Stanovich, 1980).[4] There were no significant correlations in the accuracy analyses.

To explore the influence of participant characteristics on the correlations between age and word frequency effects, partial correlations were computed for age and the word frequency effect in each task, partialing out the subject variables one at a time (see Table 9). Controlling for participant variables did not change the relationship between age and word frequency effects, except that controlling for vocabulary eliminated the one significant correlation between age and the word frequency effect in the pronunciation task. Thus, it appears that the age effect in this task was tied to vocabulary knowledge. This was also the case for the other lexical variables (see Table 8), for which partialing vision, OSpan, and vocabulary had no systematic influence on the correlations.

Accuracy analyses. Accuracy analyses were conducted by considering the proportion of correct trials out of total trials, excluding any RT or z score outliers or microphone errors. Because the dependent measure was binary at the subject level, we conducted logistic regression analyses for each variable in each task. The correlation between age and word frequency accuracy, Exp(B), is presented in Table 7 and was not significant for any task, nor were the correlations between the quadratic effect of age and word frequency accuracy when controlling for the linear effect of age. Correlations between age and word frequency betas also remained nonsignificant (or in a few cases, marginally significant) even after partialing out the participant characteristics (see Table 9).

Alternative Measures of Word Frequency

In the current study, log SUBTLEX word frequency (Brysbaert & New, 2009) has been reported throughout. However, most earlier studies have used Kučera and Francis's (1967) word frequency norms, which are based on a small, outdated corpora and have demonstrably lower predictive power (see Balota et al., 2004; Brysbaert & New, 2009) than more modern word frequency norms based on larger corpora, such as Hyperspace Analogue to Language (HAL; Lund & Burgess, 1996), the Educator's Word Frequency Guide (Zeno, Ivens, Millard, & Duvvuri, 1995), and Subtitle Frequency (SUBTLEX; Brysbaert & New, 2009). It is important to explore alternative measures of frequency because it is possible that there are cohort effects, as older word frequency norms (e.g., Kučera & Francis, 1967) may be more consistent with older adults' frequency of exposure than younger adults' frequency of exposure (see Balota et al., 2004). Therefore, we performed analyses across a set of word

[4] It was somewhat surprising that vocabulary showed a robust correlation with the word frequency effect in animacy judgment and pronunciation, but only marginally in lexical decision. This is consistent with some prior research (e.g., Butler & Hains, 1979; Lewellen, Goldinger, Pisoni, & Greene, 1993; Sears, Siakaluk, Chow, & Buchanan, 2008; Yap, Balota, et al., 2012). Yap, Balota, et al. (2012) posit that this may be because of word frequency effects being driven by lexical processes in pronunciation, but decision processes in lexical decision. If this is indeed the case, one might wonder why word frequency effects in animacy judgment (also a decision task) are correlated with vocabulary in the current study. Sears et al. (2008) note that word-frequency/reading-skill correlations emerge only when pseudohomophones are the distractors in lexical decision; they suggest that participants lower in reading skill rely on phonological representations to distinguish between words and nonwords, but cannot do so when distractors are phonologically identical to real words, and hence have to rely more heavily on semantics. Our animacy judgment places a heavy load on semantics and thus appears to be consistent with this possibility.

Table 9
Subject-Level Partial Correlations Between Age and Word Frequency Betas

Control variables	Correlations with *z* score beta weights			Correlations with accuracy Exp(B)		
	AJT WF	LDT WF	PRN WF	AJT WF	LDT WF	PRN WF
None (age only)	.024	.005	.178*	.000	.099	–.123
Short Blessed Test	.035	.007	.203*	.000	.110	−.122
Vision	.034	−.030	.193*	.000	.055	−.041
Education	−.001	.008	.153	.000	.106	−.126
OSpan	.020	.086	.298**	.174	.069	−.173
Vocabulary	−.117	−.040	−.019	.000	.102	−.144
Reading per week	.025	.014	.177*	.000	.105	−.128
Vision, education, vocabulary	−.091	−.048	−.002	.000	.057	−.072
Vision, OSpan, vocabulary	−.108	.012	.110	.094	.002	−.111

Note. AJT = animacy judgment task; WF = word frequency; LDT = lexical decision task; PRN = pronunciation task; OSpan = operation span and reading/week stands for self-reported hours read per week.
* $p < .05$. ** $p < .01$.

frequency norms including Kuĉera and Francis in order to directly examine the generalizability of the obtained results.[5]

Across HAL word frequency (Lund & Burgess, 1996), the Educator's Word Frequency Guide (Zeno et al., 1995), and Kuĉera and Francis (1967) norms, results were similar with respect to the correlation between age and the word frequency effect. No significant linear or quadratic relationships between age and word frequency emerged with any of the word frequency measures, with one exception: In the pronunciation task, log HAL word frequency effects significantly and linearly decreased (approached zero) as age increased ($r = .238$, $p = .004$), with no significant quadratic trend. Like the findings with log SUBTLEX word frequency, this correlation was eliminated when vocabulary was controlled for ($r = .022$, $p = .794$). In sum, the lack of correlation between age and word frequency effects does not appear to be specific to any particular word frequency metric.

Dichotomizing Age With Extreme Groups

In order to make contact with prior studies and explore the influence of the common practice of dichotomizing extreme levels of age, we next compared younger and older adults' word frequency effects in *z* scores. We repeated the item- and subject-level analyses including only younger (Ages 18 to 25 years; $n = 32$) and older (Ages 65+ years; $n = 39$) adults.

Item-level regression analyses run on average *z* scores for younger and older adults demonstrated similar beta weights for word frequency: animacy judgment, $\beta_{young} = -.309$, $\beta_{old} = -.301$; lexical decision, $\beta_{young} = -.429$, $\beta_{old} = -.414$; and pronunciation, $\beta_{young} = -.278$, $\beta_{old} = -.285$. Similarly, an independent samples *t* test on the subject-level word frequency beta weights indicated no difference between younger and older adults for any task (all $ps > .43$). An additional interesting observation from the dichotomized item-level analyses is that R^2 values were comparable for younger and older adults; thus, constancy in word frequency effects is not because of increasing variability with older age in the current study.

Task-Specific Processing

As noted earlier, much of the prior work in visual word recognition lacks consideration of the task-specific processes brought online by task demands (see Balota & Yap, 2006). Because each participant completed three tasks in the present study with the same stimuli, we can explore the extent to which task modulates the size of the predictor variables. Because task-specific modulation of performance, such as biasing dimensions of the stimulus that are likely to be relevant for a specific task, may involve attentional control, one might predict that older adults show less task-specific modulation of performance because of age-related changes in attentional control. Alternatively, one might expect some preservation of this attentional control because the tasks are language-based and the stimulus dimensions are more highly familiar to older adults than young (Jenkins, Myerson, Joerding, & Hale, 2000). If older adults' performance is not as influenced by task demands compared with younger adults, this would provide additional evidence for attentional breakdowns, even within the domain of language.

To explore this issue, correlations among the three tasks were assessed. These correlations were run for overall raw RTs and accuracy, and for the subject-level word frequency beta weights for *z* scores and accuracy, and are presented in Table 10. It is striking that word frequency effects in *z* scores were *not* highly correlated across the tasks. This highlights the task-specific processing engaged for each task (see Balota & Yap, 2006). Importantly, though, there is no evidence for changes in the task-specific processing as a function of age, because partialing out age and computing correlations among tasks did not modulate any of the observed correlations. Thus, these results suggest that the extent to which individuals bring online specific processes for specific tasks is consistent across the age spectrum examined.

[5] We also examined words falling in the lower half of SUBTLEX word frequency. If the benefit of word frequency to recognition approaches asymptote, the lower half of the frequency spectrum should show a stronger influence of word frequency. We therefore explored the word frequency effect as a function of age for only the less-frequent half of the stimuli ($n = 591$). Word frequency effects were *smaller* overall for the lowest frequency words, with mean βs = –.10, –.11, and –.10 for animacy judgment, lexical decision, and pronunciation, respectively (relative to mean βs = –.15, –.20, and –.16 for animacy judgment, lexical decision, and pronunciation, respectively, with all words included). The word frequency effect still did not change as a function of age in any task, with the exception of a marginally significant correlation with age in the pronunciation task ($r = .139$, $p = .093$).

Table 10
Subject-Level Intertask Correlations

Dependent measure	AJT & LDT	AJT & PRN	LDT & PRN
Overall RT	.767***	.415***	.541***
Overall accuracy	.742***	.568***	.480***
Word frequency effect, *z* scores	.112	.250**	.224**
Word frequency effect, accuracy	.000	.000	−.008

Note. AJT = animacy judgment task; LDT = lexical decision task; PRN = pronunciation task; RT = response time.
** $p < .01$. *** $p < .001$.

General Discussion

The current study used a multitask approach with a large set of items to better understand how visual word recognition changes across the adult age spectrum. Overall, the results indicated that the effects of a large set of targeted variables (e.g., length, word frequency, orthographic neighborhood) were quite consistent with effects observed in pronunciation, lexical decision, and animacy judgment tasks in the available literature. Armed with this pattern of data, we were then able to explore how these targeted variables may change as a function of age and correlated variables.

Although we examined a wide set of lexical variables, we focused on the influence of word frequency, a hallmark of visual word recognition, across the adult life span. Past studies that have investigated the word frequency effect in young and older adults have produced varying patterns of effects. This inconsistency in the literature is potentially because of task differences, stimulus selection issues, and potential participant differences, all of which were controlled or examined.

The primary finding in the present study was a lack of an association between age and the word frequency effect in RTs and accuracy, with one exception in the pronunciation task. However, even in the pronunciation task, there was no effect of age once vocabulary was controlled. The finding of no relation between age and word frequency persisted across multiple tasks (animacy judgment, lexical decision and pronunciation, with vocabulary controlled), analyses (subject-level and item-level), measures of word frequency (SUBTLEX, HAL, Zeno, and Kučera & Francis, 1967), and dependent variables (*z* scores, raw RT, accuracy), as well as through the addition of participant characteristics (vision, working memory, vocabulary, and others). We shall now turn to potential interpretations of the overall finding of age constancy in lexical processing across the adult age spectrum.

First, although there is age constancy in the word frequency effect, it is possible that disparate processes associated with age and the word frequency effect may act in a compensatory manner. For example, the accumulation of experience with words and additional vocabulary items leads to a smaller word frequency effect (Chateau & Jared, 2000; Keuleers, Diependaele, & Brysbaert, 2010; Scarborough, Cortese, & Scarborough, 1977), whereas engaging in more holistic processing or the unitization of lexical representations may lead to a larger word frequency effect (Spieler & Balota, 2000). These opposing relations might manifest as roughly equivalent word frequency effects for younger and older adults. We attempted to examine these potentially opposing processes in the current study by measuring the influence of other variables thought to influence the word frequency effect. If these age-related processes produce opposing influences of word frequency, we should be able to measure this with our correlated variables. If, on the other hand, compensatory mechanisms are engaged to keep the visual word recognition system in an adaptive state, we might see evidence of that in modulation of the age and word frequency relationship by correlated variables. There may be some suggestion of this in the pronunciation task, in which there was a modest correlation between age and word frequency betas, which was eliminated when vocabulary was controlled. This may suggest that the observation of smaller word frequency effects is instead because of increasing vocabulary, but it is unclear why this would occur in the pronunciation task only. Aside from this, the results were quite clear in showing no change in the word frequency effect across age, even when taking into consideration changes in major variables such as vision, working memory, and vocabulary.

Second, it is possible that we may not have adequately measured the influence of variables that contribute to word frequency effects, or that the participants we recruited were atypical. Although we may have missed or inadequately measured important participant characteristics, those that we did include are well-established in prior literature (the Short Blessed Test, vision, OSpan, Shipley vocabulary, number of years of education). Importantly, the participants in the current study were not from select samples of college students and highly educated older adults, but all came from the same targeted community sample.

It is also possible that we did not have the best word frequency measure to look at age-related differences, as there are potential cohort effects. Specifically, it is possible that recent word frequency norms are more likely tied to the younger and middle-aged individuals than our older adults. Hence, we examined the influence of multiple word frequency norms (including the older Kučera & Francis [1967] norms, which may be more tuned to the older adult lexicon), and indeed there was no evidence that the word frequency norms influenced the findings.

Relation to Prior Literature

One goal of the current study was to examine characteristics of prior studies to see whether they influence the relationship between word frequency and age. As noted, one potential source of inconsistency was participant characteristics; other studies use college students and healthy community-dwelling retirees (both populations who participate very often in psychological studies). The current study attempted to reconcile this by measuring participant characteristics and recruiting a fresh set of diverse participants. This was critical because it is possible to obtain different signatures of processing when distinct populations are used (even in cases of two different college student populations, as in Yap, Tse, & Balota, 2009). Although the participant variables were related to word frequency, especially in animacy judgment and pronunciation, participant characteristics did not modulate the relation between age and word frequency.

Another potential source of inconsistencies in prior literature is the task used to draw inferences. Clearly, task had a large influence on the main effect of variables—word frequency betas differed by as much as 0.15 for item-level *z* scores and 0.24 for item-level accuracy across tasks. Importantly, the overall response latencies and word frequency betas were not strongly correlated across tasks. Most theoretical accounts lack consideration of task-specific influences, and relatively few studies employ more than one task. Studies such as the current one highlight the importance of using multiple tasks to triangulate task-general and task-specific processes to build theories and models (Grainger & Jacobs, 1996).

Finally, although there has been considerable inconsistency in the literature regarding the relationship between age and word frequency in visual word recognition, it should also be noted that a number of studies have found that there is no change in the word frequency effect as a function of participant age, most notably those from Allen and colleagues (Allen, Bucur, Grabbe, Work, & Madden, 2011; Allen, Madden, & Crozier, 1991; Allen, Madden, Weber, & Groth, 1993; see also Tainturier, Tremblay, & Lecours, 1989; Whiting et al., 2003). The present results converge with results from Allen and colleagues and mitigate the concern that word frequency differences between age groups actually reflect vocabulary differences. In most studies, including the Allen and colleagues studies, the older adults had higher vocabulary scores than the younger adults (i.e., they argued that controlling for vocabulary would then confound intelligence), and hence one potential concern is that this may have produced the age equivalence in word frequency effect. However, given the convergence of the present results with these studies, it appears that this is not the case.

What Model Can Account for the Observed Effects?

One benefit of the current study is the ability to relate the observed patterns to model predictions. The primary finding of constancy in word frequency effects across the adult life span is consistent with Murray and Forster's (2004) rank order hypothesis, which posits that rank frequency of an item, not absolute frequency, is predictive of performance. Rank frequency, but not absolute frequency, should stay consistent across the life span, so Murray and Forster (p. 724) explicitly predict that one should see equivalent word frequency effects across the life span. The observed results are also potentially consistent with the transmission deficit hypothesis (Burke & MacKay, 1997; Burke & Shafto, 2008; MacKay et al., 1999). Because this theory posits age-related changes in frequency effects because of the decay of one-to-many activation transmission, it predicts that differing word frequency effects as a function of age should be seen for language production only (e.g., word retrieval from memory, not from the word displayed on-screen, as in the current study).

Constant word frequency effects across the life span are inconsistent with a logogen-type account (e.g., Morton, 1969), because an unembellished version of this account posits increasing exposure to words reaching eventual asymptote. Because a logogen-type account does not specifically make predictions about age, one might posit additional age factors that work in opposition to, and age-related change in, the word frequency effect. It is also inconsistent with theory that lexical representations become more holistic over time (as in Samuels et al., 1978 and Spieler and Balota, 2000). The current results are inconsistent with several theoretical models in their current instantiations, but one benefit of this work is to provide another benchmark for these models to incorporate into future instantiations.

Conclusions

Although the focus in the present study was on age-related changes in the word frequency effect, the present results have more general implications for visual lexical processing in the adult lexicon. Specifically, as shown in Table 9, not only was there little change in the word frequency effect across age, but there is very little change in any of the lexical variables across age. This constancy in the influence of word variables across the life span, even after the influence of participant characteristics is controlled for, is noteworthy. It appears that once the adult lexicon is developed, there is relatively little change in the nature of lexical processing, even in the face of changes in vocabulary, attention, and vision across the life span. This is suggestive of an adaptive lexical processing system that settles into a relatively stable state, even though there are age-related changes in relevant parameters. Another consideration may be that older adults' increased experience with language processing combats age-related attentional decline in tasks in the lexical domain (versus the spatial domain, as in, Lima, Hale, & Myerson, 1991). There is some evidence for this in the psychological refractory period paradigm. Specifically, Allen et al. (2002) and Lien et al. (2006) reported evidence that older adults are more likely to produce simultaneous processing of lexical information and response selection than younger adults.

Of course, one needs to be cautious here to not extend this conclusion beyond the tasks and variables studied here, because there are other processes involved in reading (e.g., eye movement, syntax processing, semantic integration) that may be affected by aging, and there may be effects of age-related changes in sensory uptake, working memory, and vocabulary on other tasks that are more demanding of sentence-level comprehension (e.g., sentence reading, as measured by eye tracking [Kliegl, Grabner, Rolfs, & Engbert, 2004; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006]; speech perception of syntactically complex sentences with or without rapid presentation [Wingfield, McCoy, Peelle, Tun, & Cox, 2006]). The current study focused on isolated visual word recognition only, a basic and well-studied building block of language. Hence, it is within the current context of a large sample of participants and large set of stimuli that there are minimal age-related changes in the nature of single-word visual lexical processing. In this light, the present results support the contention that at least this important building block of visual language processing system has privileged protection against the onslaught of aging.

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