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Perception-Production Asymmetries in Homophone Spelling:

The Unique Influence of Aging

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Abstract

Objectives: This research investigated three potential asymmetries in the production and perception of homophone spelling errors: aging, homophone dominance, and priming. A homophone spelling error occurs when a contextually appropriate word (*beet*) is replaced with its homophone (e.g., *beat* glaze). Two experiments investigated young and older adults' written production and detection of these errors.

Method: Participants wrote sentences (Experiment 1) or detected errors in sentences (Experiment 2) containing a dominant homophone (*beat*) or subordinate homophone (*beet*). Homophones were preceded by a prime (*neat*) that shared orthography with the contextually inappropriate homophone (*beat*) or by an unrelated control word (*fun*).

Results: Results revealed an aging asymmetry in production and detection as a function of dominance. Older adults made more errors than young adults when producing dominant homophones but fewer errors in producing subordinate homophones. In contrast, older adults consistently made fewer errors than young adults when detecting homophone errors. Independent of aging, dominance had similar effects on production and detection, with more errors on subordinate homophones. Priming had asymmetric effects different from aging by increasing errors in production but not detection.

Discussion: These results suggest aging uniquely dissociates perception and production of homophone spelling and demonstrate circumstances under which aging benefits language processing.

Keywords: aging, homophone spelling, perception-production asymmetry

Introduction

Investigations of age-related differences in language processing have revealed a curious asymmetry between older adults' perception and production of spoken language (e.g., Burke, MacKay, & James, 2000). Specifically, the ability to perceive and comprehend speech generally remains stable in old age when sensory deficits are controlled and the cognitive demands of the task are minimized (e.g., Sommers, 1997; Wingfield, Peelle, & Grossman, 2003). In contrast, older adults' greater difficulty in producing speech is a hallmark of normal aging (e.g., Burke & Shafto, 2004; Mortensen, Meyer, & Humphreys, 2006). Although considerably less research has been conducted on older adults' production of written words, a similar age-linked asymmetry has been demonstrated for spelling (e.g., MacKay, Abrams, & Pedroza, 1999; Shafto, 2010). Within these studies, perception is defined in terms of detection processes, such as the detection of a word as either correctly or incorrectly spelled, whereas production is measured via the accuracy of producing a word's spelling. In general, these studies showed that older adults have greater difficulty when producing spellings compared to detecting misspellings.

The purpose of the present study was to investigate whether an age-linked asymmetry between production and perception occurs for homophones using a written spelling (production) task and an error detection (perception) task. Unlike most spelling studies which often involve low-frequency words that can differ in familiarity for young and older adults, homophones (e.g., *beat*, *beet*) are words that both age groups typically know how to spell and can differentiate their meanings. We also explored whether age is unique in dissociating homophone error production and detection, or whether orthographic priming and homophone dominance differentially influence both tasks.

One theory of cognitive aging, the Transmission Deficit (TD) model (MacKay & Burke, 1990), proposes a specific mechanism to explain age-linked asymmetries in language processing. Words are represented in a hierarchical architecture of nodes, with each node having connections to semantic, lexical, phonological, and orthographic representations (see in Figure 1). Perception is a *bottom-up* process, starting with phonological nodes (when perceiving speech) or orthographic nodes (when perceiving written words). Activation spreads in parallel from these lower-level nodes upward to connected lexical nodes, which then transmit activation to the semantic system. In contrast, production is a *top-down* process, which ultimately requires the activation and retrieval of phonological/orthographic information. For example, in single-word production tasks, activation starts with nodes in the semantic system, proceeds from the lexical node to be produced, and spreads downward.

The "input/output asymmetry" (Burke & MacKay, 1997) between perception and production that accompanies aging is explained by the number of connections that converge onto a node. During perception, the structure of the network allows for converging activation from multiple phonological/orthographic nodes onto a single lexical node. In contrast, successful production is dependent on activation across single connections from the lexical node to each of its phonological/orthographic nodes. According to the TD model, as people age, the strength of connections between all nodes in the network weakens, decreasing the speed and amount of activation transmitted between nodes. Older adults' perception is less vulnerable to the effects of these transmission deficits because of the converging activation from multiple sources (i.e., orthographic nodes in the case of written perception) onto the lexical node, which cumulatively allows for their weaker connections to transmit enough activation to enable perception of a presented word. In production, activation of the phonological and orthographic nodes is

vulnerable to age-related transmission deficits because of those singular connections, which are weakened and cannot be offset by other connections.

While the TD model can explain age-linked asymmetries both in speech and in writing, the representation of homophones and their interactions with aging have not been well-specified. Because homophones share phonology but differ in semantics, orthography, and sometimes syntax (part of speech), studying homophones provides an opportunity to understand the influence of age on semantic, syntactic, phonological, and orthographic representations as well as interactions between different levels of representation (White, Abrams, Palm, & Protasi, 2012). White et al. (2012) asked young and older participants to write auditorily-presented sentences containing homophones in an attempt to induce homophone spelling errors, where a contextually-appropriate homophone is misspelled. In these sentences, the target homophone (e.g., *blew*) was preceded by an unrelated word or a semantic prime related to the meaning of the alternate spelling (*sky*, which is related to *blue*). Both age groups showed equivalent semantic priming of errors, i.e., a greater likelihood of spelling the error *blue* when preceded by *sky*, and suggesting that activation of the homophone's lexical node during homophone production is preserved in old age.

In contrast, the effect of a target homophone's sound-to-spelling regularity did interact with age. While both age groups made more errors on homophones with an irregular spelling than a regular spelling, this increase in errors due to irregularity was greater for young adults than older adults. Young adults' greater reliance on spelling regularity is consistent with previous research where homophones were spelled in isolation (Cortese, Balota, Sergent-Marshall, & Buckner, 2003) and supports a view where older adults rely more on semantics to compensate for deficits in lower-level phonological and orthographic representations (MacKay & Burke,

1990). Indeed, although older adults made fewer errors overall than young adults, White et al. proposed that their reduced errors actually reflect an impairment in orthographic encoding, which results in less activation to an alternate (error) homophone.

The present studies extended research on homophone spelling by assessing whether age is unique in dissociating production and perception, relative to two variables that have previously been shown to influence homophone production in young adults: orthographic priming and homophone dominance. When orthographic primes (e.g., *neat*) precede homophones (*beet*) in a sentence (as in "...*neat to serve beet glaze*"), young adults make more errors, writing *beat* in place of *beet* (White et al., 2008, 2010). A homophone's dominance also influences the likelihood of producing an error. Homophone dominance corresponds to the meaning that is more commonly used in everyday language, with dominant homophones (*beat*) being more common than subordinate homophones (*beet*). Errors are more likely to occur when subordinate homophones are contextually-appropriate, i.e., dominant homophones (*beat*) are spelled in place of their subordinate counterpart (*beet*). Although neither priming nor homophone dominance have been investigated in homophone detection, research with young adults using a variable correlated with homophone dominance, word frequency, has shown that error detection is typically worse for low-frequency homophones (e.g., Jared, Levy, & Rayner, 1999).

Experiment 1: Production of Homophone Errors

The present experiment investigated whether older adults' production errors are influenced by orthographic primes and homophone dominance. Orthographic primes, which share orthography with the *incorrect* (i.e., contextually-inappropriate) homophone, have been shown to increase homophone spelling errors in young adults (White et al., 2008, 2010). However, orthographic priming of homophones in older adults has been limited to single-word priming techniques where the lower-frequency spelling of a homophone is primed (Gomez,

2002). With respect to homophone dominance, research on spelling homophones in isolation has shown that older adults are more likely to spell subordinate homophones compared to young adults (Davis et al., 1990; Rose, Yesavage, Hill, & Bower, 1986). White et al. (2012) also found that older adults made fewer errors than young adults when subordinate homophones were contextually appropriate.

Method

Participants

Forty-eight young adults (aged 18-22; 34 females) participated for partial course credit or extra credit in their Introductory Psychology or upper-level psychology classes. Forty older adults (aged 60-91; 26 females) from the Charleston, SC community were paid \$10 for participation. Participants completed a questionnaire assessing various demographics and took a 25-item multiple-choice vocabulary test. Older adults were given the Mini-Mental State Exam (MMSE, Folstein, Folstein, & McHugh, 1975) to assess any cognitive impairment, and only participants who scored 25 or above were included in analysis, resulting in the exclusion of one older adult. Table 1 (left side) presents means and standard deviations for these various demographic characteristics. All participants reported English as their first language. Young adults had fewer years of education, $t(85) = 5.20, p < .001$, lower vocabulary scores, $t(85) = 5.41, p < .001$, and slightly larger backward digit spans, $t(83) = 1.75, p = .09$, than older adults. Young and older adults did not differ on self-reported health, $p = .52$, or forward digit span, $p = .24$.

Materials

Sentence Writing Task. A total of 48 homophone pairs were identified as having a dominant (i.e., primary) and a subordinate (i.e., secondary) meaning. Thirty-nine pairs (81%)

were chosen from White and Abrams' (2004) dominance norms, with dominant homophones consistently being rated as more common ($M_{young} = 73.6$, $M_{older} = 70.0$) than subordinate homophones ($M_{young} = 14.3$, $M_{older} = 14.6$). Another nine homophone pairs were categorized as dominant or subordinate according to the frequency norms developed by Zeno, Ivens, Millard, and Duvvuri (1995). Additionally, across all 48 pairs, dominant homophones were higher in frequency ($M = 290.00$, $SD = 1138.39$) than subordinate homophones ($M = 8.13$, $SD = 17.72$).

Two sentences were created for each of the 48 homophone pairs, with one sentence written so that the dominant homophone was correct (i.e., contextually-appropriate), and with one sentence written so that the subordinate homophone was correct (see top row of Table 2). Each sentence included either an orthographic prime or an unrelated (i.e., unprimed) control word that preceded the target homophone by four to eight words ($M = 6.0$, $SD = 1.37$). Orthographic primes overlapped in phonology and orthography with the incorrect homophone. Control words did not share orthography or phonology with either homophone but were similar to the prime in length ($M = 5.23$ letters, $SD = 1.48$ for prime words; $M = 5.61$ letters, $SD = 1.98$ for control words, $t(95) = 1.92$, $p > .06$), and made sense in the sentence context. Most primes (e.g., *teacher*) overlapped in the critical differentiating part of the homophone (e.g., *beech/beach*), but often shared other letters with the homophone (e.g., *-ch*). Counterbalancing prime condition (prime, control) and homophone dominance (dominant, subordinate) resulted in each participant encountering 48 sentences, 12 sentences of each prime/dominance type. Sentences were audiotaped by a female experimenter and played over computer speakers via a program written in Visual Basic 5.0.

Homophone Recognition Test. Participants' knowledge of the spelling and meaning of individual homophones was assessed with a homophone recognition test. One sentence (different

from the sentences in the experiment) was written for each of the 96 homophones and included a blank in place of the contextually appropriate homophone (e.g., *The musician _____ the drum,* or *The _____ soup was great*). Participants chose the correct homophone for each sentence by circling one of the two homophones (*beat, beet*) listed after each sentence. Counterbalancing of the two sentence versions and homophone order resulted in four versions of the recognition test.

Procedure

Young adults were tested in groups of one to ten per session, and older adults were tested individually or in groups of two. Participants completed the demographic questionnaire and the written cognitive tests and were individually tested for forward and backward digit span and MMSE. Instructions for the sentence writing task asked participants to start writing as soon as they heard each of the auditorily-presented sentences. A tone indicated each upcoming sentence, was followed by a one-second pause, and then the sentence was played. After 30 seconds, another tone was played to indicate that participants should cease writing. At that time, the sentence was repeated if any participant requested to hear the sentence again, and an additional 15 seconds were given to write. Participants were instructed to legibly print or write in cursive and were asked to not mark through any written responses, but to write any new or changed word(s) in the space above each sentence.

Following administration of the sentence writing task, participants completed the homophone recognition test at their own pace.

Results

The dependent measure was the mean proportion of homophone spelling errors (e.g., writing *beat* in place of *beet*). Analyses excluded homophones that were incorrectly identified on the homophone recognition test by each participant ($M_{\text{young}} = .64\%$ of homophones, $M_{\text{older}} =$

.70%). Other exclusions included target homophones that were misheard as a different word or not written anywhere in the sentence (8.2% for young adults, 7.2% for older adults), and targets corresponding to primes that were misheard as a different word, not produced, or misspelled (0.6% additional trials for young adults, 3.4% for older adults).

For all results, only analyses where $p < .05$ were considered significant. Discussion of the results from Experiment 1 is delayed until the General Discussion so that production-perception asymmetries can be considered together. Means and standard deviations for the percent of homophone spelling errors by prime condition and target homophone dominance are reported in Table 3. A 2 (age group: young, older) x 2 (prime condition: prime, control) x 2 (target homophone dominance: dominant, subordinate) repeated-measures analysis of variance (ANOVA) was performed on the mean proportion of homophone spelling errors by participants (F1) and by items (F2). There was no main effect of age group, but there was a main effect of target homophone dominance, $F_1(1, 85) = 143.16$, $MSE = .03$, $p < .001$, $\eta^2 = .32$, $F_2(1, 90) = 22.48$, $MSE = .06$, $p < .001$, $\eta^2 = .36$, which was moderated by a Target Homophone Dominance x Age Group interaction, $F_1(1, 85) = 4.23$, $MSE = .01$, $p = .043$, $F_2(1, 90) = 5.41$, $MSE = .01$, $p = .022$ (see Figure 2). Planned comparisons indicated that young adults made fewer errors on dominant targets than older adults, $p_1 = .038$, $\eta^2 = .05$, $p_2 = .057$, $\eta^2 = .08$, but made equivalent errors on subordinate targets, $p_1 = .234$, $\eta^2 = .01$, $p_2 = .106$, $\eta^2 = .02$.

To verify that this interaction was not driven by a floor effect arising from older adults making so few errors on dominant homophones, we computed each target homophone's proportional change in errors as a function of age group, separately for dominant and subordinate homophones, calculated as $\frac{(M_{young} - M_{older})}{\text{Max}(M_{young}, M_{older})}$, i.e., the percent change in errors for young adults relative to older adults (see also White et al., 2012). An independent samples t-test between

dominant and subordinate homophones' proportional change in errors revealed a significant effect of dominance, $t(91) = 1.97, p = .05, \eta^2 = .05$. Subordinate homophones had a proportionately larger increase in errors for young adults relative to older adults ($M_{\text{increase}} = 10\%$), while dominant homophones had a proportionately larger increase in errors for older adults than young adults ($M = -6\%$). This analysis therefore confirmed the ANOVA showing that young adults have an advantage when spelling dominant homophones and conversely revealed an advantage for older adults when spelling subordinate homophones.

In addition, both age groups made more errors on subordinate targets than on dominant targets, $p_{1S} < .001, \eta^2_{\text{young}} = .56, \eta^2_{\text{older}} = .34, p_{2S} < .001, \eta^2_{\text{young}} = .77, \eta^2_{\text{older}} = .46$, but this effect of target dominance was larger for young adults ($M_1 = 13.3\%$) than for older adults ($M_1 = 9.4\%$). Again, this interaction was verified by an independent samples t-test between young and older adults conducted on proportional change in errors, this time as a function of homophone dominance, and revealed a significant effect of age group, $t(85) = 2.61, p = .013, \eta^2 = .07$. Young adults had a proportionately larger increase in errors for subordinate homophones relative to dominant homophones ($M = 65\%$) than did older adults ($M = 45\%$).

With respect to priming, there was a main effect of prime condition, $F_1(1, 85) = 12.07, MSE = .01, p < .001, \eta^2 = .03, F_2(1, 90) = 11.09, MSE = .01, p < .001, \eta^2 = .03$, which was moderated by a Prime Condition x Target Homophone Dominance interaction, $F_1(1, 85) = 4.14, MSE = .03, p = .045, F_2(1, 90) = 8.05, MSE = .01, p = .006$. Planned comparisons indicated priming for both dominant targets (significant in the participant analysis only); $M_{1\text{priming}} = 1.8, p_1 = .025, \eta^2 = .29, p_2 = .654, \eta^2 = .01$.) and for subordinate targets ($M_{1\text{priming}} = 5.7, p_1 = .003, \eta^2 = .09, p_2 < .001, \eta^2 = .23$), with a larger priming effect for subordinate targets. There was no significant Age Group x Prime Condition interaction or three-way interaction.

Experiment 2: Detection of Homophone Errors

Experiment 2 provided a platform for investigating potential asymmetries with age, dominance, and priming in production-perception by exploring the impact of these three variables on *detection* of homophone spelling errors. With respect to age, the present methodology is unique, as previous studies on age differences in spelling detection required participants to identify correctly-spelled and misspelled written words presented in isolation and sometimes with speeded presentation rates (e.g., MacKay et al., 1999; Shafto, 2010). The reading task used in this experiment is similar to that used in literature on young adults' proofreading. In these studies, participants are given a sentence or passage and are instructed to read for meaning. Participants either cross out words that do not make sense in context or their eye movements are tracked during reading (e.g., Coltheart, Laxon, Rickard, & Elton 1988; Jared et al., 1999; Rayner, Pollatsek, & Binder, 1998). In these tasks, homophone errors (e.g., *beat* written in place of *beet*) are less likely to be detected than spelling controls (e.g., *beer*). Word frequency (which is correlated with dominance) has been shown to influence young adults' detection errors such that young adults were worse at detecting errors when the contextually-appropriate homophone was low frequency compared to when it was high frequency (Jared et al., 1999). However, these proofreading studies have not yet investigated the influence of orthographic primes on error detection. Furthermore, these studies focused on accuracy (or eyetracking) but have not used response times to detect errors as an additional dependent measure. Given evidence that older adults emphasize accuracy over speed in the laboratory (e.g., Rabbitt, 1979; Salthouse, 1979), we measured both accuracy and response times for detecting homophone spelling errors in the present experiment.

Method

Participants

Sixty young (ages 18-25; 50 females) and 60 older (ages 62-80; 33 females) adults were recruited and compensated as in Experiment 1. Three female young adults were removed from analyses due to self-reported dyslexia or learning disabilities, and one male older adult was removed for not following directions. Participants completed the same questionnaires and cognitive tests described in Experiment 1.

Means and standard deviations for young and older adults' demographic characteristics can be found on the right side of Table 1. Similar to Experiment 1, older adults reported more years of education than young adults, $t(114) = 6.25, p < .001$, and had greater vocabulary scores, $t(114) = 9.21, p < .001$. The age groups did not differ on self-reported ratings of health ($p = .77$), forward digit spans ($p = .17$), or backward digit spans ($p = .28$).

Materials

This experiment used the same 48 homophone pairs, primes, control words, and sentences as Experiment 1 (shown in Table 2). However, because sentences were visually presented, homophones could appear in one of three ways: correct, incorrect-foil, incorrect-pseudohomophone. When correct, the homophone was contextually appropriate for the sentence. Homophones were sometimes presented correctly to ensure that homophones were not always incorrect, but these correct sentences were not analyzed further. In sentences containing an incorrect spelling, the homophone was either a foil (i.e., an alternative spelling of the homophone that was contextually inappropriate for the sentence, e.g., *beat* for a sentence where *beet* is correct) or a pseudohomophone (i.e., a nonword that was phonologically identical to the homophone; e.g., *bete*). Pseudohomophones were included in this experiment so that trials with incorrect spellings were not always true homophones. In this experiment, the variable

“homophone dominance” was defined by which target homophone was presented in the “correct” sentence. Primes always overlapped in orthography with the foil in an attempt to increase errors. Counterbalancing resulted in participants seeing 48 sentences, four of each type of prime condition/correct homophone dominance/homophone error type combination.

Forty-eight randomly presented filler sentences that did not contain a homophone or pseudohomophone were included to reduce participants’ awareness that the experiment was testing detection of homophone errors. Half of these filler sentences were grammatically correct, while the other half contained different types of grammatical errors (verb tense, number, pronoun use, or possession).

Homophone Recognition Test. Experiment 2 used the same homophone recognition test as Experiment 1.

Procedure

Sentences were administered to participants on individual computers with 17-inch monitors via a program written in Visual Basic 5.0. The detection task asked participants to read each sentence carefully and determine if the sentence was grammatically correct or if it contained any word that made it ungrammatical. Examples of some of the error types (described above) that would make a sentence ungrammatical were provided. Although no example of a homophone error was provided in the instructions, participants were told that an incorrectly spelled word was considered an error. Participants were told that each sentence either contained just one error or no error at all. They were instructed to either accept the sentence as being grammatically correct by using the mouse to click a button that read “NO ERRORS” or to reject the sentence as grammatically incorrect by clicking on the word that made the sentence ungrammatical. After clicking on the word believed to be incorrect, a box appearing at the top of

the screen prompted participants to type in the correct version of the word. Participants were asked to *only* change words to make them grammatical and not to introduce any new words when making corrections.

The experimenter assisted participants in correcting three practice sentences, one containing a true spelling error (not a homophone error), one containing a verb tense error, and one containing no errors at all. Following the practice sentences, participants attempted to correct the homophone and filler sentences, which alternated in presentation. A given homophone or filler sentence was randomly selected for each trial. Following administration of this error detection task, participants completed the homophone recognition test.

Results

Analyses excluded homophones that were not identified correctly on the homophone recognition test by each participant ($M_{\text{young}} = .74\%$ of homophones, $M_{\text{older}} = .53\%$), and homophone errors that were detected as incorrect but changed to a different word (e.g., *weight* changed to *waist*; $M_{\text{young}} = 1.4\%$, $M_{\text{older}} = 2.6\%$).

Accuracy in detecting a homophone error and response time to detect a homophone error served as the primary dependent variables. Although some previous research on homophone error detection in young adults used percentage of undetected errors as the primary dependent variable (e.g., Jared et al., 1999), these studies only reported an accuracy measure. In order to compare RTs and accuracy directly in the present data, we conducted analyses on proportion of correct error detection (i.e., correctly detecting a foil or pseudohomophone error) rather than missed errors. Detections were considered correct if participants clicked on the foil or pseudohomophone. Detections were considered incorrect if participants either clicked “NO ERRORS” or clicked on a different (non-homophone) word in the sentence.

Detection Accuracy

A 2 (age group: young, older) x 2 (error type: foil, pseudohomophone) x 2 (correct homophone dominance: dominant, subordinate) x 2 (prime condition: prime, control) ANOVA was performed on the proportion of accurately detected errors (see top of Table 4). Correct homophone dominance refers to the dominance of the correct (not presented) homophone. For example, in the sentence, “Jamie thought it would be fun to serve chicken with beat glaze at her dinner party”, the correct homophone (beet) is subordinate. There was a main effect of age group, $F_1(1, 114) = 23.55$, $MSE = .05$, $p < .001$, $\eta^2 = .17$, $F_2(1, 93) = 54.82$, $MSE = .01$, $p < .001$, $\eta^2 = .05$, such that older adults ($M_1 = 95.1\%$) were more accurate at detecting errors than young adults ($M_1 = 88.2\%$). There was also a main effect of correct homophone dominance, $F_1(1, 114) = 69.62$, $MSE = .03$, $p < .001$, $\eta^2 = .11$, $F_2(1, 93) = 24.55$, $MSE = .07$, $p < .001$, $\eta^2 = .21$, where people were more accurate in detecting an error when a dominant homophone was correct ($M_1 = 96.4\%$) than when a subordinate homophone was correct ($M_1 = 86.9\%$). A main effect of error type, $F_1(1, 114) = 34.40$, $MSE = .02$, $p < .001$, $\eta^2 = .04$, $F_2(1, 93) = 8.26$, $MSE = .06$, $p = .005$, $\eta^2 = .03$ revealed better accuracy in detecting pseudohomophones ($M_1 = 94.5\%$) than in detecting foil homophones ($M_1 = 88.8\%$). The prime condition main effect was not significant.

The ANOVA revealed an Age Group x Correct Homophone Dominance interaction (see Figure 3), $F_1(1, 114) = 12.64$, $MSE = .03$, $p < .001$, $F_2(1, 93) = 20.69$, $MSE = .01$, $p < .001$, showing that both age groups were more accurate when dominant homophones were correct than when subordinate homophones were correct, $p_1s < .001$, $\eta^2_{\text{young}} = .54$, $\eta^2_{\text{older}} = .40$, $p_2s < .001$, $\eta^2_{\text{young}} = .24$, $\eta^2_{\text{older}} = .16$, but this effect was larger for young adults. Furthermore, older adults were more accurate than young adults both for sentences where the dominant homophones were correct, $p_1 < .023$, $\eta^2 = .05$, $p_2 = .005$, $\eta^2 = .16$, and where the subordinate homophones were

correct, $p_1 < .001$, $\eta^2 = .19$, $p_2 < .001$, $\eta^2 = .47$, but this difference was larger for the latter condition. No other interactions were significant.

The above analyses focused on error detection, regardless of whether the participants corrected the error with the correct homophone (e.g., correctly produced *beat* after detecting that *beet* was an error). Because there were instances where participants subsequently produced the incorrect spelling of the homophone (e.g., *erns* for *urns*), we verified that the above results did not change once excluding these cases. The percent of correct detections that were changed to an incorrect spelling was similar for young and older adults: 3.3% and 1.7% for foils, respectively, and 5.6% and 5.7% for pseudohomophones, respectively. Excluding these cases revealed an identical pattern of results as reported above.

Response Times. Response times (in seconds) to click on the foil or pseudohomophone were recorded. Three older adults were removed from these analyses due to problems in using a mouse. Means and standard deviations were calculated for young adults' ($M = 9.88$ sec, $SD = 7.67$) and older adults' ($M = 13.32$ sec, $SD = 12.78$) detection response times, defined as the time between onset of sentence presentation and participants' mouse click on the foil or pseudohomophone. Detection response times above 2 SD from each age group's mean were removed from analyses (4.6% of trials for both young and older adults).

A 2 (age group: young, older) x 2 (error type: foil, pseudohomophone) x 2 (correct homophone dominance: dominant, subordinate) x 2 (prime condition: prime, control) ANOVA was conducted on mean response times for correctly detected errors (see bottom of Table 4). A main effect of age group, $F_1(1, 107) = 14.31$, $MSE = 65.14$, $p < .001$, $\eta^2 = .01$, $F_2(1, 84) = 89.77$, $MSE = 3.84$, $p < .001$, $\eta^2 = .09$, indicated that young adults ($M_1 = 7.02$ sec) were faster to detect errors than older adults ($M_1 = 9.09$ sec). A main effect of correct homophone dominance, $F_1(1,$

107) = 52.83, $MSE = 6.50$, $p < .001$, $\eta^2 = .08$, $F_2(1, 84) = 9.56$, $MSE = 20.12$, $p = .003$, $\eta^2 = .01$, showed faster detection for sentences where the dominant homophone was correct ($M_1 = 7.43$ sec) than for sentences where the subordinate homophone was correct ($M_1 = 8.68$ sec). A main effect of error type, $F_1(1, 107) = 4.43$, $MSE = 4.61$, $p = .038$, $\eta^2 = .01$, $F_2 < 1$, showed faster detection of pseudohomophones ($M_1 = 7.90$ sec) than foils ($M_1 = 8.21$ sec). The prime condition main effect did not reach significance.

There was a significant Age Group x Prime Condition x Error Type interaction (in the participant analysis only), $F_1(1, 107) = 4.01$, $MSE = 4.35$, $p = .048$, $F_2 < 1$. Following up this complex interaction with respect to age differences revealed that both age groups were faster to detect pseudohomophones than foils when there was a prime in the sentence, $F_1(1, 107) = 5.21$, $MSE = 3.96$, $p = .024$, $\eta^2 = .04$, but this difference in error detection only emerged for young adults ($t_{\text{young}}(54) = 2.21$, $p = .031$, $\eta^2 = .08$; $t_{\text{older}}(55) = .77$, $p = .44$, $\eta^2 = .01$) when there was a control word in the sentence.

As with accuracy, we verified that the response time analyses did not change after excluding trials where the correct homophone's spelling was not produced after identifying an error. Excluding these cases revealed an identical pattern of response time results as reported above.

General Discussion

These experiments reveal new insights about the nature of asymmetries between production and detection of homophones, the uniqueness of the aging asymmetry, and implications of these asymmetries for the TD model. Consistent with previous research on both speech and spelling, aging produced asymmetric effects on homophone spelling, with larger age-related deficits on production (defined here as misspelling production) than perception (defined

as misspelling detection). Specifically, older adults made more errors than young adults when producing the correct spellings of dominant homophones. Age-related deficits in homophone production are consistent with the TD model (e.g., MacKay & Burke, 1990; MacKay et al., 1999) in that production requires activation of orthography across single connections predicted to weaken with age (see Figure 2). Interestingly, the change score analyses revealed an age-related advantage in producing subordinate homophones. This advantage is consistent with White et al. (2012), who also found that older adults made fewer errors than young adults when producing subordinate homophones, and suggests that older adults may have stronger connections to subordinate homophones than young adults. This interaction of dominance with aging on production of homophone errors parallels findings that older adults are worse than young adults when spelling high-frequency, but not low-frequency, words (MacKay & Abrams, 1998; but see Shafto, 2010).

In contrast to production, older adults exhibited better detection of homophone errors than young adults, particularly when the dominant homophone was the error (and the subordinate homophone was correct), demonstrating a (rarely-documented) age-related *advantage* in detection. One possible explanation for older adults' increased detection accuracy (for both foils and pseudohomophones) is a potential speed-accuracy tradeoff, as older adults' increased accuracy was accompanied by slower response times to detect errors relative to young adults (see also Shafto, 2010). These studies therefore highlight the importance of measuring response speed in perception tasks to better understand age-related asymmetries more broadly. Another explanation could be older adults' increased years of experience with language which may lead to more familiarity with alternate linguistic forms, i.e., the subordinate homophones. Alternatively, older adults' superior error detection may suggest age differences in older adults'

activation of phonology during reading. It is widely accepted that there are two routes for accessing a word's meaning when reading (see Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001, for a review) – a “direct route” that allows readers to go directly from print (orthographic nodes) to meaning (lexical node), and an “indirect route” that mediates orthography through phonology (as illustrated in Figure 1). Evidence suggests that reading proficiency in young adults influences which route is used such that better readers are more likely to use the direct route than poorer readers (e.g., Doctor & Coltheart, 1980; Jared et al., 1999). In a homophone error detection task, use of the indirect route makes successful error detection less likely by activating the homophone's phonology, making it easier to accept the error as appropriate. Because older adults were more accurate at detecting homophone errors than young adults, older adults may be more likely to bypass activating the homophone's phonology and use the direct route during reading, consistent with Cortese et al.'s (2003) suggestion of older adults' greater reliance on semantic-to-orthographic connections during spelling production. Theoretically, these asymmetry findings suggest that older adults may have stronger connections to subordinate homophones than young adults in their representations of homophones (see Davis et al., 1990; Gomez, 2002; Rose et al., 1986; White et al., 2012), resulting in similar influences of dominance on production and detection.

Unlike aging, homophone dominance had similar effects on production and detection of errors. For production, more errors occurred when attempting to produce subordinate homophones, resulting in spelling the dominant homophone in place of its subordinate partner. Similarly, error detection (of both foils and pseudohomophones) was slower and less accurate when the correct homophone was subordinate, i.e., both age groups were less likely to detect an error that was a dominant homophone. Both findings are consistent with previous literature on

young adults' homophone production (White et al., 2008) and homophone proofreading (e.g., Coltheart et al., 1988; Jared et al., 1999) and extend them to older adults. The lack of a dominance asymmetry in production and detection of homophones can be accounted for by the TD model, where perception and production share the same nodes. Due to less frequent use, subordinate homophones have weaker connections to their phonological and lexical nodes than dominant homophones. In production, this results in greater difficulty activating the necessary orthography when attempting to produce the subordinate homophone. In detection, if reading involves use of the indirect route, dominance serves to influence how quickly the correct homophone's orthography gets activated, a necessary requirement for detecting the mismatch between orthography and semantics (sentence context) (e.g., Jared et al., 1999).

A priming asymmetry between detection and production emerged but was different in nature from the aging asymmetry in that priming increased production errors (reliably for subordinate homophones) but had no effect on detection. The priming asymmetry can be explained within the TD model in terms of connections being strengthened via priming. When an orthographic prime is encountered, it transmits activation top-down to its phonological and orthographic nodes, which in turn spread activation bottom-up to connected lexical nodes, strengthening the connections to words sharing that orthography. Priming the incorrect homophone's orthography is relevant to homophone production, which relies on top-down connections. Because the prime shares orthography with the incorrect homophone, the recently-strengthened connections make the incorrect homophone more available for production, resulting in an error. Errors are particularly likely to occur when priming the dominant homophone for a subordinate target because connections to the dominant homophone are already stronger than those to the subordinate homophone, and priming then provides an even greater boost in

activation to the dominant homophone, resulting in an error when spelling subordinate homophones. In contrast, priming the subordinate homophone's orthography is less reliable (evidenced by a nonsignificant priming effect in the item analysis) and less likely to influence the spelling of dominant targets, whose connections to orthography are strong and likely to get sufficient activation for production independent of the prime. These findings are consistent with previous research showing orthographic priming of homophones with young adults (White et al., 2008, 2010). Furthermore, both age groups exhibited priming to the same degree, similar to age-equivalent semantic priming effects on homophone production (White et al., 2012). The lack of priming in detection suggests that within the TD model, producing a prime may strengthen connections more strongly than reading a prime. This asymmetry could arise because perceiving words (e.g., reading) occurs more often than producing words (MacKay, 1987, p. 121), and thus priming has a stronger effect on production because those top-down connections are generally weaker than the bottom-up connections used for perception. Bottom-up connections may require additional priming to have an effect on spelling detection.

In conclusion, the present study has documented age-linked asymmetries in a new domain (homophone spelling) and has shown the uniqueness of age in specifying this input-output asymmetry. Using this paradigm, a more positive picture of aging has emerged, one where older adults have a cognitive advantage (in detection) and where age-related declines in production are not universal. Future research should continue to explore age-related asymmetries to gain a better understanding of the circumstances under which aging benefits language processing.

Acknowledgements

This research were supported by a Sigma Xi Grant-in-Aid of Research, awarded to Sarah Zoller, and by a College of Charleston Summer Undergraduate Research Fellowship, awarded to Sarah Zoller and Katherine White. Segments of Experiment 2 were reported in Sarah Zoller's senior thesis, which appears in the 2007 issue of the College of Charleston's *Chrestomathy: Annual Review of Undergraduate Research*. Portions of this research were also presented at the Cognitive Aging Conference in 2008. We thank Gregory Palm, Ashley Ladd, and Leisy Ruddock for assistance with data collection.

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Table 1

Means (and Standard Deviations) for Young and Older Adults' Demographic Characteristics in Experiments 1 and 2.

| Variable | Experiment 1 | | Experiment 2 | |
|------------------------|--------------|--------------|--------------|--------------|
| | Young Adults | Older Adults | Young Adults | Older Adults |
| Age | 19.44 (1.17) | 73.16 (6.19) | 19.09 (1.56) | 71.14 (5.21) |
| Education (years)* | 13.83 (1.27) | 16.08 (2.44) | 13.36 (1.36) | 16.31 (3.35) |
| Vocabulary (max = 25)* | 15.48 (3.22) | 19.49 (3.69) | 14.19 (3.21) | 19.73 (3.26) |
| Health (max = 10) | 7.50 (1.81) | 7.74 (1.52) | 7.89 (1.42) | 7.81 (1.55) |
| Forward digit span | 7.27 (1.14) | 6.95 (1.39) | 6.91 (1.33) | 7.27 (1.46) |
| Backward digit span | 5.23 (1.17) | 4.76 (1.32) | 4.86 (1.20) | 5.14 (1.49) |
| MMSE (max = 30) | | 27.64 (2.79) | | 28.25 (1.40) |

Note. Asterisks indicate significant differences (for both experiments) between the age groups, $p < .05$.

Table 2

Example Primed and Control Sentences for Dominant and Subordinate Homophones used in Experiments 1 and 2.

| Target Homophone | Homophone Dominance | |
|------------------|---|--|
| | Dominant | Subordinate |
| Correct | There are only a couple of <i>feet</i> (steps) before I cross the line and <u>beat</u> my opponent. | Jamie thought it would be <i>neat</i> (fun) to serve chicken with <u>beet</u> glaze at her dinner party. |
| Foil | There are only a couple of <i>feet</i> (steps) before I cross the line and <u>beet</u> my opponent. | Jamie thought it would be <i>neat</i> (fun) to serve chicken with <u>beat</u> glaze at her dinner party. |
| Pseudo-homophone | There are only a couple of <i>feet</i> (steps) before I cross the line and <u>bete</u> my opponent. | Jamie thought it would be <i>neat</i> (fun) to serve chicken with <u>bete</u> glaze at her dinner party. |

Note. In Experiment 1, sentences were presented auditorily, so the target homophone was only presented in one way, e.g., /bit/. In Experiment 2, each target homophone was visually presented in one of three ways (correctly spelled, incorrectly spelled as a foil, or incorrectly spelled as a pseudohomophone), as shown here. Primes are italicized, control words are in parentheses, and target homophones (correct, foil, and pseudohomophone) are underlined.

Table 3

Means (and Standard Deviations) for the Percent of Homophone Spelling Errors (e.g., writing beat instead of beet) Produced by Young and Older Adults in Experiment 1

| Age Group | Homophone Dominance | |
|------------------|---------------------|-------------|
| | Dominant | Subordinate |
| Young Adults | | |
| Prime | 2.8 (5.2) | 17.2 (13.3) |
| Control | 0.4 (2.0) | 12.6 (10.7) |
| <i>% Priming</i> | 2.4 | 4.6 |
| Older Adults | | |
| Prime | 3.7 (7.1) | 16.0 (13.7) |
| Control | 2.6 (4.9) | 9.2 (12.2) |
| <i>% Priming</i> | 1.1 | 6.8 |

Table 4

Means (and Standard Deviations) for Young and Older Adults' Detection Accuracy (% Correctly Detected Errors) and Response Times (in seconds) in Experiment 2.

| Age Group | Dominant | | Subordinate | |
|---------------------|-------------|-------------|-------------|-------------|
| | Foil | Pseudo | Foil | Pseudo |
| Young Adults | | | | |
| Prime | 90.8 (15.6) | 98.2 (6.4) | 78.2 (23.3) | 83.6 (18.5) |
| Control | 92.3 (16.7) | 98.7 (5.6) | 76.6 (26.8) | 87.0 (19.4) |
| Older Adults | | | | |
| Prime | 97.2 (10.6) | 99.0 (5.4) | 89.4 (16.5) | 92.7 (14.7) |
| Control | 95.8 (10.2) | 99.4 (4.3) | 90.0 (18.0) | 97.4 (7.9) |
| Young Adults | | | | |
| Prime | 6.43 (2.36) | 6.34 (2.47) | 7.81 (2.68) | 7.28 (2.60) |
| Control | 6.66 (2.28) | 6.27 (2.10) | 8.10 (3.23) | 7.26 (2.59) |
| Older Adults | | | | |
| Prime | 8.65 (3.57) | 8.05 (3.47) | 9.84 (4.73) | 9.31 (4.26) |
| Control | 8.23 (3.83) | 8.78 (3.74) | 9.93 (4.48) | 9.91 (5.91) |

Note. Top half of table reports accuracy and bottom half reports response times.

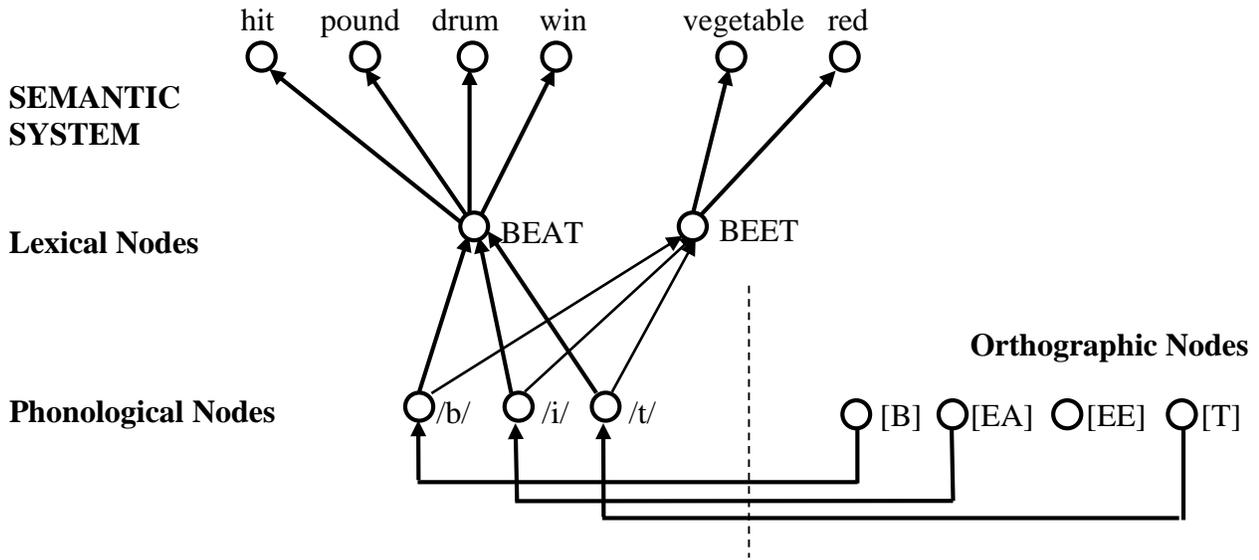
Figure Captions

Figure 1. A simplified representation of the TD model's lexical, phonological, and orthographic nodes, and spreading activation during perception (top) and production (bottom). When reading the homophone, activation (indicated by arrows) travels bottom-up from *beat*'s orthography to its lexical node and then to nodes in the semantic system. When producing the homophone, activation spreads top-down from the semantic system to the phonological nodes for *beat*. Activation then travels laterally to orthographic nodes, which are more strongly connected for dominant homophones.

Figure 2. The percent of homophone production errors made by young and older adults for dominant and subordinate homophone targets in Experiment 1.

Figure 3. The percent of homophone detection errors made by young and older adults when dominant and subordinate homophones were contextually appropriate (correct) in Experiment 2. The figure presents percent of detection errors (instead of percent accuracy) so that direct comparisons can be made with Figure 2, which presents percent of production errors from Experiment 1.

Flow of bottom-up activation during perception of *beat*.



Flow of top-down activation during production of *beat*.

