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An Examination of Age-Related Changes in the Control of Lexical and Sublexical Pathways in Mapping Spelling to Sound

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Abstract

The current study investigated the extent to which young and older adults are able to direct attention to distinct lexical processes in mapping spelling onto sound. Young and older adults completed either a speeded pronunciation task (reading aloud words) or a regularization task (pronouncing words based on spelling-to-sound correspondences, e.g., pronouncing PINT such that it rhymes with HINT) in order to bias either processing of lexical, whole-word information, or sublexical, spelling-to-sound mapping, respectively. Both younger and older adults produced reduced word frequency effects and lexicality effects in the regularization task compared to the normal pronunciation task. Importantly, compared to younger adults, older adults produced exaggerated effects of task (i.e., pronunciation vs. regularization) on the observed frequency and lexicality effects. These results highlight both the flexibility of the lexical processing system and the influence of changes in the influence of the underlying lexical route due to additional 50 years of reading experience and/or changes in attentional control.

Keywords

Word frequency; Word regularity; Attention; Lexicality; Word Recognition; Aging

One of the goals of psycholinguistic research is to uncover structural/modular constraints of the lexical processing system. Recently, however, there has been increased interest in how attentional control systems can bias specific components (e.g., processing pathways) of the lexical processing system (see Balota & Yap, 2006). Indeed, there is experimental evidence that distinct processing pathways can be influenced by local list context (e.g., Baluch & Besner, 1991; Cohen-Shikora & Balota, 2013; O'Malley & Besner, 2008; Reynolds, Besner, & Coltheart, 2011; Scaltritti, Balota, & Peressotti, 2013). In the current study we focus on the processes involved in generating a pronunciation from an orthographic code. Although the implications of attentional bias are important for virtually all models of speeded pronunciation, the present study uses the general dual route architecture (e.g., Coltheart et al., 2001) as a guiding framework. In addition, as described below, we gain leverage on better understanding such pathway biases by examining both younger and older adults, who

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likely have differences in underlying strengths of pathways along with changes in attentional control systems.

According to the dual route framework, there are two routes to the generation of pronunciation from orthography, a lexical route and a spelling-to-sound conversion process. In the Coltheart et al. (2001) Dual Route Cascade model, the lexical route is based on parallel activation of letter units which map onto lexical units, which after reaching threshold afford the appropriate pronunciation for the lexical unit. In contrast, the sublexical pathway begins to compute the pronunciation based on spelling to sound principles in a serial left to right manner, at least in English. Although these two pathways typically converge on the same output, there are some instances where there is conflict between the two pathways. For example, words such as “PINT” (an exception to the standard spelling-to-sound rules) receive correct output from only the lexical pathway, because the sublexical pathway would produce the output of PINT such that it rhymes with HINT. In addition, because there is no direct output for nonwords, these items would be primarily pronounced by the sublexical route, within a dual route framework.

The role of word frequency provides an important constraint on the dual route perspective. Because word frequency is based on the frequency of the whole word unit in the language, it exerts an influence on the lexical pathway, with relatively little direct influence on the sublexical route. This latter assumption is important in predicting a frequency by regularity interaction. Specifically, high frequency words are relatively less influenced by spelling to sound regularity (e.g., HAVE vs SAVE), relative to low-frequency words (e.g., PINT vs HINT). Presumably, for high-frequency words the lexical route is completed so fast that its output occurs before competition from the slower sublexical route. Of particular interest in the current study is whether the lexical route might become relatively stronger across the adult lifespan with the extra decades of language processing.

Biasing the Contributions of the Lexical and Sublexical Pathways in Pronunciation

Midgley-West (1979, as described in Monsell, 1991) was one of the first researchers to investigate the influence of local bias on the two processing pathways. Specifically, an exception word (e.g., “wolf”) was embedded at the end of a list of nonwords. After reading aloud an entire list of nonwords, thirty-nine percent of participants incorrectly pronounced “wolf” such that it rhymed with “golf.” The notion is that the nonwords biased participants to use the sublexical pathway and hence pronounced “wolf” via spelling-to-sound correspondences.

The results from Midgley-West inspired a series of studies using list context to bias the lexical and sublexical pathways. For example, Zevin and Balota (2000) had participants pronounce sequences of nonwords or low-frequency exception words in the spirit of the Midgley-West paradigm. The results indicated that the effects of lexical variables (word-frequency and imageability) were larger when the lexical pathway was biased by the low-frequency exception words, and sublexical variables (regularity and lexicality) were larger when the sublexical pathway was biased by the nonwords. Reynolds and Besner (2005) used

mixed lists of nonwords and exception words in a consistent sequence of two from each category (e.g., nonword, nonword, exception word, exception word repeating). They found “stay” trials (prior trial from same lexical category) were pronounced faster and more accurately than “switch” trials (prior trial from other lexical category), which suggests that participants biased processing along the targeted pathway producing a performance advantage when remaining within the same processing pathway. Additional evidence of pathway biasing has been found in other experimental paradigms (e.g., pure nonword or exception word lists versus mixed lists containing both, Monsell, Patterson, Graham, Hughes, & Milroy, 1992; presence versus absence of nonwords in a list, O’Malley & Besner, 2008; use of standard nonwords versus pseudo-homophone nonwords, Reynolds, Besner, & Coltheart, 2011; semantic priming task contrasting related versus unrelated primes, Scaltritti et al., 2013) and task contexts (e.g., Persian word reading given different list contexts, Baluch & Besner, 1991; past tense conjugation given different list contexts, Cohen-Shikora & Balota, 2013)¹. As discussed below, there may be differences across methods of inducing pathway bias, but to date, this issue has not been directly explored in the literature.

Direct Control of Lexical and Sublexical Pathways

The above studies used experimental context to bias processing pathways. However, it is also possible to influence processing pathways more directly via task instructions rather than implicitly via context manipulations. This approach is akin to the Stroop color-naming paradigm wherein one attempts to use task instructions to select the weaker pathway (color naming) over the more dominant pathway (word reading). Balota, Law, and Zevin (2000) used this approach and compared reading aloud of words and nonwords across standard pronunciation (read these stimuli aloud) and novel regularization instructions (read these stimuli aloud as if you were sounding them out, pronouncing each item according to standard spelling-sound correspondences). The regularization instructions were designed to investigate the degree to which participants could direct attention to the sublexical pathway. Half of the stimuli in this study were nonwords which should also encourage the use of the sublexical pathway. The results indicated that in the standard pronunciation task, participants pronounced words faster than nonwords (the lexicality effect) and for words there was the typical frequency by regularity interaction noted above, i.e., high-frequency words were relatively uninfluenced by regularity whereas low-frequency words were influenced by regularity. Remarkably, participants given regularization instructions showed an elimination of the lexicality effect and a *reversal* of the word frequency effect. First regarding the elimination of the lexicality effect, Balota et al. argued that this is consistent with the notion that participants were indeed primarily attending to the sublexical pathway in output, thereby eliminating the influence of the lexical pathway. More importantly, with respect to the reversal of the word-frequency effect, the authors argued that high frequency words were slower in the regularization task than low-frequency words, because the lexical pathway is stronger and more difficult to suppress for high-frequency words. Importantly,

¹Although there appears to be converging evidence that the pathways can be biased to some extent, there is also evidence that at least some of the effect is due to changes in time criterion to output a response based on the difficulty of the list context (see for example Kinoshita & Lupker, 2002).

these results indicate that there is considerable flexibility in the modulating the lexical processing pathways involved, which is incompatible with a more modular view of the visual word recognition system.

Recently, Ihnen (2013) used the regularization paradigm to compare individuals with different levels of reading efficiency in use of the lexical and sublexical pathways. In particular, Ihnen compared young adults (college students) with children (8–10 year olds), who were relatively new readers and hence may be more biased to rely on the sublexical processing pathway. The results indicated that young adults replicated the Balota et al. (2000) pattern, in which the word frequency and lexicality effects are robust in the pronunciation task but in the regularization task, the lexicality effect was eliminated and the word-frequency effect was reversed. Remarkably, she found that children were actually *faster* in the regularization task compared to the young adults, in spite of their typical pattern of slowed responding in a variety of other speeded tasks. This pattern of results is consistent with the notion that the relative strength of the sublexical pathway is stronger in children, since they have not had as much experience processing words which would bias the lexical pathway. Hence, children can more easily control the lexical pathway, whereas, for adults, this is relatively difficult to control. Ihnen also found that children showed decreased sensitivity to the lexical characteristics of the words relative to young adults. For example, Ihnen found that children showed a smaller word frequency effect in the standard pronunciation task than adults, and furthermore that the word frequency effect was reversed to a smaller degree in the regularization task than it was for the adults. This pattern nicely follows from the observation that the strength of the lexical and sublexical pathways differ across developmental stages.

The current study is an extension of the Ihnen (2013) study to investigate controlled use of processing pathways at the older end of the aging spectrum. Although Ihnen reported a developmental trajectory on the use of the lexical and sublexical pathways, it is quite possible that one would find a different pattern in a comparison of young versus older adults. In particular, because of the extra 50 years of lexical processing, one might expect older adults to show larger effects of the lexical processing pathway, as opposed to the sublexical pathway observed in the Ihnen study. This would manifest as stronger sensitivity to word frequency, and stronger modulation of the frequency effect, for older adults relative to younger adults. However, it is also possible that younger and older adults have comparable lexical and sublexical processing pathways, i.e., the lexical and sublexical pathways have stabilized in strength by young adulthood and do not change across the adult age range, which would manifest as similar results for younger and older adults. Indeed, there is recent evidence from a conceptually similar study that there is no difference in the influence on past tense conjugation of list context (stimulus type) for younger and older adults (Cohen-Shikora & Balota, 2013). It is possible that the pathways in the lexical processing pathway have been optimized by young adulthood, and there is relatively little age-related change in the attention to these processing pathways. This would manifest as similar results for younger and older adults; that is, a replication of Balota et al. (2000) across both age groups.

Method

Participants

A total of 132 participants were in this study; 72 in the pronunciation task (34 younger adults, 38 older adults) and 60 in the regularization task (31 younger adults, 29 older adults). The younger adults (ages 18–29, $M = 19.95$) were recruited from the Washington University undergraduate subject pool and received course credit or cash for their participation. The older adults (ages 58–90, $M = 76.53$) were recruited from the Aging and Development subject pool and were given \$10 an hour for their participation. Younger adults had fewer years of education on average ($M = 13.94$ years) than older adults ($M = 15.12$ years), $t(127) = 3.30$, $p < .01$. Younger adults also had lower scores on the Shipley vocabulary test ($M = 33.98$) than older adults ($M = 35.93$), $t(101) = 3.48$, $p < .01$. Importantly, across the regularization and pronunciation tasks, participants did not differ on education ($t(61) = 1.20$, $p = .236$, for younger adults and $t(64) = 0.13$, $p = .90$, for older adults) or Shipley vocabulary score ($t(55) = 0.51$, $p = .61$, for younger adults and $t(44) = 0.55$, $p = .58$, for older adults).

Design

Age (young vs. old) and Task (regularization vs. standard pronunciation) were between-participant factors, with lexicality (word vs. nonword) as a within-participant factor. In addition, nested within words, both word frequency (low vs. high) and regularity (regular vs. exception) were within-participant factors.

Stimuli

Stimuli were taken from Balota et al. (2000) and are listed in the Appendix below. The 119 stimuli consisted of 80 words (20 in each of the four conditions created by factorially crossing frequency with regularity; see Table 1 for lexical characteristics) and 39 nonwords. Participants were also given 49 practice trials consisting of 30 exception words, 8 regular words, and 5 nonwords. Practice stimuli were primarily exception words in order to give sufficient practice for the regularization task. All stimuli were randomly intermixed in the practice and experimental blocks.

Procedure

The procedure closely followed Balota et al. (2000). Participants were given instructions specific to their randomly-assigned task condition (pronunciation or regularization). Those in the pronunciation task were instructed to read aloud the words or nonwords presented onscreen, whereas those in the regularization task were instructed to read all stimuli as if they conformed to regular spelling-to-sound correspondences, similar to the sounding-out method of reading. Participants in both tasks were given the practice list, during which the experimenter answered questions about or corrected their regularization responses.

The following sequence of events occurred on each trial: (a) a 330-millisecond (ms) blank screen was presented, (b) the target stimulus was presented until the voicekey detected a response, and (c) a 1500-ms blank screen appeared, during which the experimenter coded the participant's response as correct, incorrect (read incorrectly in either task, or not

regularized in the regularization task), or microphone error (erroneous triggering of the microphone).

Results

In order to minimize the influence of outliers, responses under 200 milliseconds (ms), over 3000 ms, and beyond three standard deviations from a participant's mean were eliminated from the forgoing analyses. This eliminated 1.2% of the trials. Microphone errors (1.8% of total trials) and incorrect trials (10.3% of total trials) were excluded from analyses of response latencies.

Because age-related differences in processing speed can compromise the interpretation of any effects of aging, we focus here on the analyses of z-transformed data. Specifically, a mean and standard deviation was calculated for each participant, and each response latency was converted to a z-score. This transformation has been shown to control for processing speed differences across age groups (see Faust et al., 1999).² The mean RTs, z-scored RT, and accuracy estimates as a function of age, task, word frequency and regularity are displayed in Table 2. Analyses were conducted on both the participant-level (F_1) and the item-level means (F_2). The results from the participant and item level analyses are largely consistent in the present results; however, in a few cases the effects do not generalize across items. Of course, the emphasis in the present study is on between participant changes in these effects, as a function of age group.

Z-Scored Response Latencies for Words

A 2 (Frequency: Low vs. High) x 2 (Regularity: Regular vs. Exception) x 2 (Task Instructions: Regularization vs. Pronunciation) x 2 (Age: Young vs. Old) mixed-factors ANOVA was conducted on the z-scores (see Figure 1). There were main effects of frequency, $F_1(1,131) = 31.50, p < .001$, partial $\eta^2 = .19$, $F_2(1,76) = 8.68, p = .004$, partial $\eta^2 = .10$; regularity, $F_1(1,131) = 36.73, p < .001$, partial $\eta^2 = .22$, $F_2(1,76) = 14.83, p < .001$, partial $\eta^2 = .16$; and task, $F_1(1,131) = 142.63, p < .001$, partial $\eta^2 = .52$, $F_2(1,76) = 62.00, p < .001$, partial $\eta^2 = .45$. These were qualified by several two-way interactions. First, the Frequency x Task interaction was significant, $F_1(1, 131) = 31.04, p < .001$, partial $\eta^2 = .19$, $F_2(1,76) = 10.60, p = .002$, partial $\eta^2 = .12$, which reflected a significant frequency effect (high-frequency words 0.24 SDs faster than low-frequency words) for the pronunciation task, $t_1(70) = 9.98, p < .001$, $t_2(78) = 4.91, p < .001$, but no frequency effect for the regularization task, $t_1(63) = 0.024, p = .98$, $t_2(78) = 0.38, p = .71$. Second, the Regularity x Task interaction was significant, $F_1(1, 131) = 5.00, p = .027$, partial $\eta^2 = .04$, $F_2(1,76) = 5.01, p = .028$, partial $\eta^2 = .06$, which reflected a smaller regularity effect in the pronunciation task (regular words 0.09 SDs faster than exception words), $t_1(70) = 6.61, p < .001$, $t_2(78) = 1.87, p = .065$, than the regularization task (regular words 0.20 SDs faster than exception words), $t_1(63) = 4.15, p < .001$, $t_2(78) = 3.87, p < .001$. The Frequency x

²It should be noted that analyses were also conducted on mean response latencies and with the exception of a significant main effect of age, $F(1,131) = 12.19, p < .001$, partial $\eta^2 = .09$, which was eliminated in the Z scored RTs, $F(1,131) < 1$. In addition, the analyses on the raw RTs did not yield an overall significant Frequency x Regularity, $F(1,131) < 1$, or Frequency x Regularity x Task, $F(1,131) = 2.18$, interactions in the raw RTs, which were significant in the Z-scored RTs (although the patterns of results were similar to the Z-scored RT, see Table 2).

Regularity interaction was also significant in the subject analyses, $F_1(1, 131) = 6.31, p = .013$, partial $\eta^2 = .05$, $F_2(1, 76) = 1.18, p = .281$, partial $\eta^2 = .02$, which reflected a larger regularity effect for the low-frequency words (regular words 0.18 SDs faster than exception words), than for the high-frequency words (regular words 0.09 SDs faster than exception words). Finally, the Frequency x Regularity x Task interaction was significant in the subject analyses, $F_1(1, 131) = 4.00, p = .048$, partial $\eta^2 = .03$, $F_2(1, 76) = 0.66, p = .420$, partial $\eta^2 = .01$, reflecting a robust Frequency x Regularity interaction in the pronunciation task, $F_1(1, 70) = 20.74, p < .001$, partial $\eta^2 = .23$, $F_2(1, 114) = 0.13, p = .724$, partial $\eta^2 = .001$, but not in the regularization task, $F_1(1, 63) < 1$, $F_2(1, 114) < 1$. These findings are consistent with the Balota et al. (2000) study, and the prediction that the regularization task involves biasing of the sublexical pathway. Importantly, the Frequency x Task x Age Group interaction was also significant in the subject analyses, $F_1(1, 131) = 4.18, p = .043$, partial $\eta^2 = .03$, $F_2(1, 76) = 1.77, p = .187$, partial $\eta^2 = .02$. As shown in Figure 1, this interaction reflects a larger influence of task on the word frequency effect in older adults than in younger adults. That is, the word frequency effect is larger in the pronunciation task in the older adults than in the younger adults, whereas in the regularization task, the word frequency effect becomes slightly more negative in the older adults than in the younger adults. However, neither of these effects are reliable when tested individually. Taken together, these provide some preliminary evidence that older adults' lexical pathway is more influenced by word frequency than younger adults.

Because the regular words produced the same response in both the regularization task and the speeded pronunciation task, we also report an analysis of these items in the test of the frequency by task interaction (see Figure 1 for the Z-scored RTs for regular words only). Indeed, the analysis produced a highly reliable Frequency x Task interaction, $F_1(1, 132) = 10.25, p = .002$, partial $\eta^2 = .07$, $F_2(1, 76) = 5.97, p = .019$, partial $\eta^2 = .14$, which reflected a robust frequency effect in the pronunciation task (0.16 SDs), but not in the regularization task (-0.003 SDs). There were no main effects or interactions with age for the regular words.

Accuracy for Words

We conducted a 2 (Frequency: Low vs. High) x 2 (Task Instructions: Regularization vs. Pronunciation) x 2 (Regularity: Regular vs. Exception) x 2 (Age: Young vs. Old) mixed-factors ANOVA on accuracy data (proportion correct out of total viable trials, excluding microphone errors). Overall, the results for the accuracy analyses were consistent with those for the Z-score RT analyses and were as follows: there were main effects of frequency, $F_1(1, 132) = 14.24, p < .001$, partial $\eta^2 = .10$, $F_2(1, 76) = 3.23, p = .076$, partial $\eta^2 = .04$; regularity, $F_1(1, 132) = 64.57, p < .001$, partial $\eta^2 = .33$, $F_2(1, 76) = 104.72, p < .001$, partial $\eta^2 = .58$; age group, $F_1(1, 132) = 7.69, p = .006$, partial $\eta^2 = .06$, $F_2(1, 76) = 28.63, p < .001$, partial $\eta^2 = .27$; and task, $F_1(1, 132) = 254.28, p < .001$, partial $\eta^2 = .66$, $F_2(1, 76) = 273.38, p < .001$, partial $\eta^2 = .78$. These were qualified by several two-way interactions and a three-way interaction. First, the Frequency x Task interaction was significant, $F_1(1, 132) = 34.20, p < .001$, partial $\eta^2 = .21$, $F_2(1, 76) = 5.32, p = .024$, partial $\eta^2 = .07$. This interaction reflected a small frequency effect (0.01 SDs) for the pronunciation task, $t(70) = 2.82, p = .006$, and a reversal of the frequency effect (-0.05 SDs) for the regularization task,

$t(64) = 5.02, p < .001$. This reversal of the word frequency effect is again an important replication of Balota et al. (2000). Second, the Regularity x Task interaction was significant, $F_1(1,132) = 44.91, p < .001$, partial $\eta^2 = .25$, $F_2(1,76) = 54.25, p < .001$, partial $\eta^2 = .42$, which reflected a smaller regularity effect (0.02 SDs) for the pronunciation task, $t(70) = 4.76, p < .001$, than the regularization task (0.22 SDs), $t(64) = 7.16, p < .001$. Third, the Task x Age Group interaction was highly reliable, $F_1(1, 132) = 12.32, p = .001$, partial $\eta^2 = .09$, $F_2(1,76) = 45.61, p < .001$, partial $\eta^2 = .38$, which reflected a much larger accuracy difference between tasks for the older adults (27.7% difference) relative to younger adults (17.7% difference). These results provide further evidence that older adults are more influenced by the lexical pathway which has to be controlled in the regularization task. The Frequency x Regularity x Task interaction was significant for the subject analyses, $F_1(1, 132) = 5.74, p = .018$, partial $\eta^2 = .04$, $F_2(1,76) = 1.14, p = .289$, partial $\eta^2 = .02$, which indicated that while the word frequency effect for both regular and exception words was modulated by task, this modulation was stronger for the exception words (0.09 SDs) than for the regular words (0.03 SDs). Finally, there was a Regularity x Age x Task interaction for the item analyses only, $F_1(1, 132) = 0.83, p = .365$, partial $\eta^2 = .01$, $F_2(1,76) = 4.09, p = .047$, partial $\eta^2 = .05$, indicating that the older adults showed a stronger influence of regularity across tasks (23% difference) than the younger adults (17% difference).

We again conducted separate analyses on the regular items to further examine the frequency by task interaction. Indeed, the analyses produced a Frequency x Task interaction in the subject analyses, $F_1(1,132) = 8.28, p = .005$, partial $\eta^2 = .06$, $F_2(1,38) = 2.03, p = .162$, partial $\eta^2 = .05$, which reflected a marginal frequency effect in the pronunciation task (0.006 SDs), $t_1(70) = 1.77, p = .081$, $t_2(78) = 1.14, p = .256$, and a reversal of the frequency effect in the regularization task (-0.03 SDs), $t_1(64) = 2.37, p = .021$, $t_2(78) = 1.52, p = .133$, for the subject analyses. For the regular words, there was also a significant or marginal main effect of age in that younger adults showed higher performance than older adults, $F_1(1,132) = 3.12, p = .08$, partial $\eta^2 = .02$, $F_2(1,38) = 6.87, p = .013$, partial $\eta^2 = .15$. Importantly, as shown in Figure 2, there was a Task x Age Group interaction, $F_1(1,132) = 5.18, p = .024$, partial $\eta^2 = .04$, $F_2(1,38) = 12.92, p = .001$, partial $\eta^2 = .25$. This interaction reflected a larger task difference in accuracy for the older adults (16% difference between pronunciation and regularization) than for the younger adults (9% difference between pronunciation and regularization), again supporting the stronger influence of the lexical processing pathway in older adults.

Z-Scored Response Latencies for the Lexicality Effect

As noted earlier, if participants could reliably attend to the sublexical pathway during the regularization task, then one would expect a reduction of the lexicality effect in the regularization task, compared to speeded pronunciation. The mean RT, z-scored RT, and accuracy estimates as a function of age, task, and lexicality are displayed in Table 3.

A 2 (Lexicality: Word vs. Nonword) x 2 (Task Instructions: Regularization vs. Pronunciation) x 2 (Age: Younger vs. Older) mixed-factors ANOVA was conducted on the Z-scored RT yielded the following reliable effects. First, there were main effects of lexicality, $F_1(1,132) = 141.53, p < .001$, partial $\eta^2 = .52$, $F_2(1,117) = 37.89, p < .001$,

partial $\eta^2 = .25$; task, $F_1(1,132) = 98.42, p < .001$, partial $\eta^2 = .43, F_2(1,117) = 15.77, p < .001$, partial $\eta^2 = .12$; and age in the subject analyses, $F_1(1,132) = 4.92, p = .028$; partial $\eta^2 = .036, F_2(1,117) = 1.24, p = .268$, partial $\eta^2 = .01$. These were qualified by a significant Lexicality x Task interaction, $F_1(1,132) = 153.43, p < .001$, partial $\eta^2 = .54, F_2(1,117) = 168.00, p < .001$, partial $\eta^2 = .59$, which reflected a significant lexicality effect in the pronunciation task (words 0.67 SDs faster than nonwords), $t_1(70) = 19.67, p < .001, t_2(117) = 11.43, p < .001$, but not in the regularization task, $t_1(64) = 0.30, p = .77, t_2(117) = 0.86, p = .39$.

Accuracy Analyses for the Lexicality Effect

Turning to the accuracy analyses, we conducted a 2 (Lexicality: Word vs. Nonword) x 2 (Task Instructions: Regularization vs. Pronunciation) x 2 (Age: Younger vs. Older) mixed-factors ANOVA on the proportion of correct trials out of the total number of trials excluding microphone errors. This analysis yielded main effects of lexicality, $F_1(1,132) = 127.85, p < .001$, partial $\eta^2 = .49, F_2(1,117) = 38.28, p < .001$, partial $\eta^2 = .25$; task, $F_1(1,132) = 132.31, p < .001$, partial $\eta^2 = .50, F_2(1,117) = 74.69, p < .001$, partial $\eta^2 = .39$; and age, $F_1(1,132) = 5.72, p = .018$, partial $\eta^2 = .04, F_2(1,117) = 14.79, p < .001$, partial $\eta^2 = .11$. These were again qualified by a significant Lexicality x Task interaction, $F_1(1,132) = 227.78, p < .001$, partial $\eta^2 = .63, F_2(1,117) = 73.69, p < .001$, partial $\eta^2 = .39$, which reflected a significant lexicality effect in the pronunciation task (words were 2.8% more accurate than nonwords), $t_1(71) = 6.10, p < .001, t_2(117) = 3.31, p = .001$, and a significant reversal of the lexicality effect in the regularization task (nonwords were 19.8% more accurate than words), $t_1(57) = 10.40, p < .001, t_2(117) = 7.76, p < .001$. There was also a Task x Age interaction, $F_1(1,132) = 8.68, p = .004$, partial $\eta^2 = .06, F_2(1,117) = 24.80, p < .001$, partial $\eta^2 = .18$, which reflected larger task differences in accuracy for the older adults (14.3% difference between regularization and pronunciation) than the younger adults (8.5% difference between regularization and pronunciation), and an Age x Lexicality interaction, $F_1(1,132) = 4.82, p = .03$, partial $\eta^2 = .04, F_2(1,117) = 6.23, p = .014$, partial $\eta^2 = .05$, which reflected a larger lexicality effect for older adults (10.1%) than younger adults (7.1%). Importantly, these interactions were also qualified by a significant Lexicality x Task x Age Group interaction, $F_1(1,132) = 8.25, p = .005$, partial $\eta^2 = .06, F_2(1,117) = 12.32, p = .001$, partial $\eta^2 = .10$ (see Figure 3), which reflected a larger task modulation of the lexicality effect for the older adults (26.9% difference between regularization and pronunciation) than for the younger adults (18.3% difference between the tasks). Younger and older adults show similar nonword performance in the pronunciation and regularization tasks ($ps > .17$), and only a 1% difference in performance for words in the pronunciation task, $t_1(69) = 1.86, p = .067, t_2(117) = 2.06, p = .042$, however, older adults were 10% worse than the younger adults on word performance in the regularization task, $t_1(63) = 3.12, p = .003, t_2(117) = 6.46, p < .001$. The larger task modulation of the lexicality effect in the older adults is consistent with the increased influence of the lexical pathway, when they are attempting to exert control over that pathway in the regularization task.

Discussion

The present results provide information regarding the extent to which individuals can exert control over lexical and sublexical processing pathways, via task instructions. We observed predicted modulations of frequency and lexicality effects when emphasis was placed on the lexical pathway in the standard pronunciation task, and clear reductions in the influence of these variables when emphasis was placed on the sublexical processing pathway in the regularization task. This pattern was reflected in the following two major observations: First, we found a robust effect of word frequency in the pronunciation task which was eliminated (in RTs) or reversed (in accuracy) given regularization task instructions. The elimination of the word frequency effect was particularly noteworthy for the regular items, which were pronounced in an identical fashion regardless of task instructions. Second, we found a robust lexicality effect in the pronunciation task which was eliminated (in RTs) or reversed (in accuracy) given regularization task instructions. The elimination or reversal of the lexicality effect is consistent with the prediction that lexicality should not influence performance if participants are able to attend to the sublexical pathway. It is important to note, however, that a full biasing of the sublexical pathway was not obtained. Specifically, as noted in Balota et al. (2000), some minimal influence of the lexical pathway is evident in lingering effects of word frequency in most analyses. If the sublexical pathway was fully biased, and the lexical pathway fully suppressed, word frequency would not exert any influence on performance (since the lexical pathway is frequency modulated, and the sublexical is not). Also, if one could fully control the lexical pathway in the regularization task, one might not expect such slow and less accurate responses in this task. However, in the regularization task one is instructed to rely primarily on the sublexical pathway, which for an adult reader of English is not a reliable pathway because of the presence of exception words. Having said this, the current results are compelling in that the effects of word frequency and lexicality are strongly modulated by an instructional manipulation in a predictable manner.

In general, younger and older adults both showed task modulations of word frequency and lexicality effects. Importantly, however, there were age differences in the results which point to a stronger influence of the lexical pathway in the older adults than the younger adults. These effects primarily occurred in the accuracy analyses, but there was some evidence in the response latencies as well. Specifically, as shown in Figure 1, the predicted change in the word frequency effect as a function of task (based on Balota et al. 2000, results) was greater in older adults than in younger adults.

Accuracy analyses showed a larger influence of task in older adults compared to younger adults. First, in the analyses including only the regular words, older adults performed more poorly than younger adults in the regularization task, however, they performed at the same level in the pronunciation task. This suggests that older adults were particularly disrupted in the regularization task, which relies more on the sublexical pathway. Similarly, age modulated the size of the lexicality effect in the regularization task much more than the pronunciation task, such that the largest age differences showed up in accuracy for words in the regularization task, in which older adults were 10% worse than the younger adults. In contrast, younger and older adults show similar nonword performance in both tasks and only

1% different performance for words in the pronunciation task. This pattern suggests that older adults are unable to fully suppress their lexical pathway in the regularization task.

There are multiple reasons why older adults may have more difficulty suppressing the lexical pathway. One possibility is that this primarily reflects strength of the two pathways, and as one ages the lexical pathway becomes stronger because of increased use. In this light, it is interesting to consider these results coupled with those of Ihnen (2013) who used the same experimental paradigm with children. As noted, Ihnen found evidence that that children's performance in the regularization task reflected greater sublexical pathway processing than young adults. In her study, children showed a weaker influence of lexical characteristics such as word frequency, and a weaker modulation of the word frequency effect in the regularization task. In contrast, in the present study, compared to younger adults, older adults produced a relatively larger influence of task on the word frequency effect. Hence, there is a novel developmental change in the influence of the lexical pathway across the two studies, in which children produce relatively small effects of the lexical pathway compared to young adults, whereas older adults produce relatively larger effects of the lexical pathway compared to younger adults. As noted, this pattern can be nicely accommodated by an increase in the strength of the lexical pathway as a function of reading experience, or alternatively, a decrease in the strength of the sublexical pathway as a function of reading experience.

A complementary interpretation of the present results and the Ihnen (2013) results is that differences in the relative strength of the lexical and sublexical pathways are coupled with differences in attentional control abilities. Specifically, there is evidence that both children and older adults show reduced attentional control compared to young adults (e.g., Dempster, 2002; Zelazo, Craik, & Booth, 2004). Reduced attentional control would manifest as a decreased ability to control a prepotent pathway (arguably, the sublexical pathway for children and the lexical pathway for older adults). The intact attentional control demonstrated by college-aged younger adults would manifest as the ability to flexibly modulate the appropriate pathway in accordance with task demands. These predictions are in line with the current results and thus there may be some contribution of attentional control in the current study, and not increased pathway reliance.

Although the present study is not able to adjudicate between these two alternatives, it is likely that both may be contributing to the intriguing developmental pattern in the Ihnen study and the present study. Clearly, further work is needed to decouple the contributions of these two theoretical accounts. Furthermore, it may be interesting to consider differences in initial reading instruction between the younger and older adults; the "whole language" method, emphasizing holistic reading for comprehension, was in place in the 1930s and 1940s, whereas the phonics method has grown in popularity since the 1950s (Adams, 1990). It is possible that our older adults may have had less phonics training in learning to read, but if anything we believe it may be just the opposite. As Rayner, Foorman, Perfetti, Pesetsky, and Seidenberg (2001) in a comprehensive review of the phonics based versus whole word reading noted: "Rather than focusing on letter-to-sound correspondences, the dominant instructional approaches for the past 20 years were meaning focused". (p. 43) Having said this, future studies of pathway control should consider individual differences in the

instructional approaches used in learning to read, as a possible mediating effect in controlling lexical and sublexical pathways.

The present pattern stands in contrast with a recent control study of past tense production by Cohen-Shikora and Balota (2013). Specifically, in this study, young and older adult participants were biased by either a sequence of regular past tense forms (e.g., live-lived, kill-killed, etc.) or irregular past tense forms (e.g., run-ran, keep-kept) to emphasize either a lexical pathway or a rule-based pathway in past tense verb generation. The results were quite clear. Both groups produced robust effects of past tense verb generation, but there was no hint of an influence of age modulating this interaction. Thus, it appears that for age differences to emerge, one might need to engage a paradigm which forces participants to directly access the non-lexical pathway, as in the present regularization task. If this were the case, then one would expect age differences in older adults if they were directly told to use the rule based pathway for irregular words, e.g., produce “runned” for run instead of ran.

In sum, the present results provide clear evidence that one can modulate the contributions of distinct processes in translating orthography to phonology in performing either a standard pronunciation task or a regularization task. Both the frequency and lexicality effects were greatly reduced in the regularization task compared to the normal pronunciation task. Importantly, these results provide evidence that older adults have an increased difficulty controlling the lexical processing pathway in the present study. These data, coupled with the Ihnen (2013) study, show a novel pattern reflecting developmental changes in the strength (and possibly control of) the lexical and sublexical processing pathways across the lifespan.

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Appendix

Regular Words		Exception Words			
High Frequency	Low Frequency	High Frequency	Low Frequency	Nonwords	
rest	mink	been	scald	answal	sape
flat	drip	move	swab	bealt	sem
gain	bail	front	choir	blasp	senade
heat	girth	some	plaid	cade	sib
keep	wane	two	soot	cobe	sopt
spot	fern	steak	gin	darp	steab
date	bait	most	chute	dode	stimp
boat	seep	done	gross	earsh	stist
side	kite	great	roll	fasher	sumple
first	bump	want	glove	frolp	toult
game	crate	word	bold	grolld	twy
plant	perk	sure	wold	mank	waim
back	dock	find	bush	martel	waty
sort	rift	whom	folk	milt	weem
spend	slurp	touch	wand	moke	whon
firm	gale	give	wash	ocean	woft
dark	scrape	show	sword	onal	worb
wish	heel	said	worm	pamtle	yeld
hope	dame	come	famine	pilk	yuke
deep	yank	mind	remind	pode

Figure 1. Mean Z-scored reaction times for Regularization and Pronunciation performance on regular words as a function of age group and frequency. Error bars reflect standard error of the mean.

Figure 2.
Mean proportion correct for Regularization and Pronunciation performance on regular words as a function of age group. Error bars reflect standard error of the mean.

Figure 3. Mean proportion correct for Regularization and Pronunciation performance as a function of age group. Error bars reflect standard error of the mean.

Table 1

Lexical Characteristics of Stimuli

Stimulus Type	Length	SUBTLEX Word Freq	OLD	PLD
High Frequency	4.15	280.24	1.40	1.18
Low Frequency	4.25	5.31	1.47	1.25
Regular Words	4.15	915.08	1.47	1.20
Exception Words	4.53	13.77	1.60	1.42

Note. SUBTLEX Word Freq = word frequency count from SUBTLEX-US (Bryshaert & New, 2009), OLD = Orthographic Levenshtein distance, PLD = Phonological Levenshtein distance (Yarkoni, Balota, & Yap, 2008), measures of neighborhood densities.

Table 2

Frequency, regularity, and task effects by age group

Younger Adults

Task	High Frequency			Low Frequency			Frequency Effect		
	RT	Z	ACC	RT	Z	ACC	RT	Z	ACC
Regular Words									
Regularization	1033	-.14	.88	1046	-.12	.90	14	0.02	-0.03
Pronunciation	540	-.35	.98	559	-.22	.98	19	0.13	0.00
Exception Words									
Regularization	1080	.03	.66	1103	.12	.74	23	0.09	-0.08
Pronunciation	539	-.37	.97	580	-.09	.95	41	0.28	0.02

Older Adults

Task	High Frequency			Low Frequency			Frequency Effect		
	RT	Z	ACC	RT	Z	ACC	RT	Z	ACC
Regular Words									
Regularization	1243	-.08	.81	1246	-.11	.84	3	-0.03	-0.03
Pronunciation	651	-.44	1.00	689	-.25	.98	38	0.19	0.01
Exception Words									
Regularization	1336	.14	.55	1291	.05	.62	-45	-0.09	-0.07
Pronunciation	664	-.40	.98	732	-.04	.97	68	0.36	0.01

Note. RT = Response time, Z = Z-scores, ACC = Proportion Correct

Table 3

Lexicality and task effects by age group

Younger Adults									
Task	Word			Nonword			Lexicality Effect		
	RT	Z	Acc	RT	Z	Acc	RT	Z	Acc
	1064	-0.04	0.80	1030	-0.08	0.96	-34	-0.05	0.16
Regularization									
Pronunciation	554	-0.26	0.97	652	0.36	0.95	97	0.62	-0.02
Older Adults									
Task	Word			Nonword			Lexicality Effect		
	RT	Z	Acc	RT	Z	Acc	RT	Z	Acc
	1258	-0.05	0.70	1265	-0.03	0.94	7	0.02	0.24
Regularization									
Pronunciation	683	-0.28	0.98	825	0.44	0.95	142	0.73	-0.03

Note. RT = Response time, Z = Z-scores, ACC = Proportion Correct