Ageing makes us dyslexic

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Structured abstract

Background: The effects of typical ageing on spoken language are well known: word production is disproportionately affected while syntactic processing is relatively well preserved. Little is known however about how ageing affects reading.

Aims: What effect does ageing have on written language processing? In particular, how does it affect our ability to read words? How does it affect phonological awareness (our ability to manipulate the sounds of our language)?

Methods & Procedures: We tested 14 people with Parkinson's disease (PD), 14 typically ageing adults (TAA), and 14 healthy younger adults on a range of background neuropsychological tests and tests of phonological awareness. We then carried out an oral naming experiment where we manipulated consistency, and a nonword repetition task where we manipulated the word-likeness of the nonwords.

Outcomes & Results: We find that normal ageing causes individuals to become mildly phonologically dyslexic in that people have difficulty pronouncing nonwords. People with Parkinson's disease perform particularly poorly on language tasks involving oral naming and metalinguistic processing. We also find that ageing causes difficulty in repeating nonwords. We show that these problems are associated with a more general difficulty in processing phonological information, supporting the idea that language difficulties, including poorer reading in older age, can result from a general phonological deficit.

Conclusions: We suggest that neurally this age-induced dyslexia is associated with frontal deterioration (and perhaps other regions) and cognitively to the loss of those executive processes that enable us to manipulate spoken and written language. We discuss implications for therapy and treatment.

Keywords: cognitive ageing, reading, phonological dyslexia, nonwords, metacognitive processes, frontostriate loop, Parkinson’s disease

Ageing makes us dyslexic

It is well known that ageing affects spoken language production, particularly word retrieval, while leaving the comprehension of spoken and written language relatively intact (Burke & Shafto, 2004; Cohen & Faulkner, 1986; Harley, Jessiman, & MacAndrew, 2011). Very little is known however about how ageing affects reading. While there of course many similarities between how we process spoken and written language, there are also many differences (Harley, 2008): written language evolved much later than spoken language, and there has been insufficient time for dedicated pathways to evolve in the same way that must have happened for speech; further, the temporal and spatial demands of processing visual language are very different from those of spoken language. Those ageing studies that there are on reading largely focus on the decline of comprehension skills and the consequences of diminished resources such as a general working impairment and less effective inhibitory processing, and show effects of the syntactic complexity of the stimuli and age of the participant (e.g. De Beni, R., Borella, Carretti, 2007; Smiler, Gagne, & Stine-Morrow, 2003; Van de Linden et al., 1999). We know even less about the effects of ageing on reading individual words, with the research emphasis on how ageing effects the allocation of resources (Lien, Allen, Ruthruff, Grabbe, McCann, & Remington, 2006). Although we know how some factors that influence word naming change with age (e.g. older adults show a larger facilitatory effect of word frequency than younger adults; Spieler & Balota, 2000), **relatively little is known about how age affects our ability to name written words orally.**

The successful development of literacy depends on the attainment of a set of skills known collectively as phonological awareness. Phonological awareness (PA) is the ability to manipulate and analyze the sounds of our language. Children's progress in learning to read follows progress in acquiring PA (Goswami, & Bryant, 1990; Swan & Goswami, 1997), and an impairment of PA in some way is associated with at least some forms of developmental dyslexia (Bailey, Manis, Pedersen, & Seidenberg, 2004; Ramus & Szenkovits, 2008). Furthermore, members of illiterate societies do not appear to have acquired PA skills (Morais, Cary, Alegria, & Bertelson, 1979). A general phonological deficit (GPD) is thought by many to be the primary cause of acquired phonological dyslexia, a condition whereby the reading of pronounceable nonwords (e.g. SLEEB) is impaired relative to words (Farah, Stowe, & Levinson, 1996; Harm & Seidenberg, 1999); however, some individuals with Alzheimer's disease show phonological dyslexia but without a more general phonological deficit (Caccappolo-van Vliet, Miozzo, & Stern, 2004).

We have previously shown that both typical and particularly pathological ageing affect PA (Harley, Jessiman, & MacAndrew, submitted): typically ageing individuals are worse at a range of tasks measuring PA, while people with Parkinson's disease (PD) fare even worse. We also showed that the degree of impairment is correlated with measures of executive processing and frontal-lobe efficiency in both groups and with the severity of the disease in the PD group (Harley, Jessiman, & MacAndrew, submitted). We argue that while much of language processing proceeds automatically without drawing heavily on attentional resources and making use of well-known neural pathways largely dedicated to language, tasks that involve a metalinguistic aspect, where language or language processing are temporarily the attentional focus, require more resources and place more general neural demands, particularly on executive processes known to be housed in the frontal lobes of the brain; we call these types of **processes** *deliberative* language (Harley et al., 2011; Rogalsky, & Hickok, 2011). Phonological awareness tasks are a clear example of processing involving executive processing, so depend on the integrity of the frontal lobes, areas thought to be particularly prone to the effects of typical ageing (West, 1996) and greatly affected by the deterioration of the frontostriate loop in PD (Harley, et al., 2011).

Given that normal reading depends on intact PA skills, it follows that if PA is disrupted by ageing, we should be able to observe subtle reading impairments in typically ageing individuals, and a more clear cut impairment in individuals with more pronounced damage to the frontostriate loop. That is, ageing should make us dyslexic - particularly phonologically dyslexic. In particular, subtle difficulties in manipulating phonology and grapheme-phoneme conversion should lead to difficulties in reading nonwords and hence result in a degree of phonological dyslexia (defined as a selective impairment in reading nonwords matched to words). **Hence we predict that any patient with frontal damage (including Broca's aphasia) will show this type of impairment. In particular,** research on the effects of Parkinson's disease (PD) (Harley et al. 2011, Harley et al., submitted) demonstrates that elderly individuals with PD display cognitive hyper-ageing as a consequence of damage to the frontostriate loop, and that this hyper-ageing particularly affects deliberative language. We therefore expect typically ageing individuals to demonstrate some symptoms of phonological dyslexia, and individuals with PD to demonstrate more profound dyslexia. The degree of **phonological** dyslexia should be correlated with the extent of frontal lobe damage.

Any impairment in reading or phonological awareness resulting from ageing that we do observe will have implications for the treatment of all elderly individuals. Treatment materials are often presented to stroke patients with **speech** difficulties in written form, given that the processing of written language might be better preserved than spoken. Our reasoning above suggests that any *specific* language impairment resulting from trauma or degenerative illness will have a *general* phonological deficit superimposed upon it, making the specific impairment more difficult to treat.

Experiment 1

Reading words and nonwords

Participants

There were 14 participants in the PD group (males = 11, females = 3, mean age 69), with diagnoses from clinical neurologists from the Tayside and Fife Medical Trusts. The mean number of years from diagnosis was 12.21 (7.86). The scores on the Hoehn and Yahr's (1967) scale of motor impairment revealed **that** 4 individuals were in stage I (mild unilateral involvement), 6 were in stage II (mild bilateral involvement) and 4 were in stage III (mild to moderate disability with impairment to balance). All PD participants carried out the experiment at peak time of efficacy of their medication. (Of course this means that we cannot rule out that some of our findings are attributable to the effects of the medication, but we think this confound is unlikely, and also unsupported by our pattern of results.) People in Hoehn and Yahr Stage III sometimes have problems with bradyphrenia and bradyarthria. We did not observe these during our testing, nor did our participants report them as features of their conditions. Further details of the severity rating of PD as indexed by scores on the introductory interview and other measures are provided in Appendix 1.

There were 14 participants in the typically ageing older adult (TAA) group (males = 2, females = 12, mean age 75), and 14 in the healthy younger adult (HYA) group (males = 5, female= 9, mean age = 28). All participants had hearing and vision corrected to normal.

Measures of educational and intellectual attainment

The full data are shown in Appendix 1.

All participants were screened to ensure there were no signs of dementia by means of the The Mini-Mental State Examination (MMSE: Folstein, Folstein & McHugh, 1975).

The mean number of years of education was 12.0 (2.70) for the PD group, 12.65 (2.54) for the TAA group and 15.0 (1.71) for the HYA group. The PD and TAA were matched for years of education with a range of 9 to 19 years for the PD group and 9 to 17 years for the TAA group. The HYA group had a range from 12 to 17 years of education which differed significantly from both the PD and TAA group ($p < 0.01$); this difference is undoubtedly due to a cohort effect of the HYA group having greater access to post-16 years education. However, there is no significant difference in intellectual or verbal ability as indexed by NART and WAIS vocabulary score ($p < 0.05$). These measures are much better indicators of attainment than mere time spent in school.

Design

This experiment used a 3x2x2 factorial design. The between-subject factor was group, comprising individuals with Parkinson's disease (PD), healthy older adults (TAA) and healthy younger adults (HYA). The first within-subject factor was word type with two levels: real words and nonwords. The second within-subject factor was consistency with two levels: consistent and inconsistent. (**Note that our pronunciations are consistent for British (and in particular Scottish) speakers; speakers of other dialects, such as speakers of American English, will**

have differing intuitions about consistency.) The dependent variables were the reaction times in milliseconds (msecs) and the number of pronunciation errors made.

Materials

We used 172 experimental stimuli in Experiment 1. The materials were taken from Glushko (1979), comprising 43 consistent words (e.g. bath, pink); 43 consistent nonwords (e.g. cath, bink), 43 inconsistent words (e.g. both, pint); and 43 inconsistent nonwords (e.g. coth, bint). Each consistent word was matched with an inconsistent word. Inconsistent words are words with different spelling-to-sound correspondences than most words with the same vowel and terminal consonants. For example, the word "have" is inconsistent because it is not pronounced in the same way as other words with similar spelling (e.g. gave, rave, save). The inconsistent words differed from the consistent words by a single letter. For example, if the consistent word ended with the letter 'l', wherever possible an inconsistent word was selected that differed from the inconsistent word only in its terminal consonant (e.g. the consistent word "deal" was matched with the inconsistent word "dead"). Using each pair of consistent and inconsistent words, nonwords such as "feal" and "fead" were constructed by replacing one of the consonants in the base word with another randomly generated consonant, maintaining pronounceability.

To control for the different onset characteristics of different phonemes (e.g. /b/ is much more abrupt than /s/), the word and nonword stimuli contained the same set of initial consonants. For example, for every word beginning with "b" there was a nonword that also began with "b". This matching enabled reaction times to be made that were uncontaminated by acoustic differences. A full listing of the word and nonword stimuli can be found in Appendix 3.

All of the stimuli were presented to the participants using an Apple Macintosh G3 laptop equipped with Cedrus Superlab software and a hand-held external microphone. Each item was displayed in black 96-point Times New Roman Font on a white background. Items remained on screen until a response so the task was self paced. Naming times were measured in milliseconds and there was a 1500 millisecond gap in between each trial. Cedrus Superlab controlled the timing of presentation of the stimuli and the recording of the voice-activated reaction times. Only first responses were scored, and a response was considered correct only if it was a completely accurate and acceptable pronunciation of the word (allowing for colloquial variation in the pronunciation of some words). For the consistent nonwords, incorrect pronunciations were those that differed from the 'consistent' ones predicted by spelling-to-sound correspondences. For the inconsistent nonwords incorrect pronunciations were those that differed from the pronunciation predicted by the matched inconsistent words.

Procedure

The 172 experimental stimuli were presented in two sets of 86 trials counterbalanced between participants. The first set of trials tested the level of consistency and comprised 43 consistent words and 43 consistent nonwords. The second set of trials tested the level of inconsistency and comprised 43 inconsistent words and 43 inconsistent nonwords. A practice set comprising 6 trials preceded each condition. At the end of each practice trial, participants were asked to press any key to commence the actual experiment.

Participants were tested individually. They were asked to sit in front of the computer at a comfortable distance, and to hold the external microphone interfaced with the computer approximately 3-4 inches from their face. The threshold of all of the participants' voices was recorded prior to testing and adjusted accordingly to ensure that the microphone was suitably sensitive to the participant's voice, and they were requested to avoid other vocal noises so as not to trigger the microphone. They were told that they were going to take part in a reading task and they would be asked to read aloud letter groups presented to them on **a computer** screen. They were informed that the words would be both real and made-up words and that they should read aloud each group of letters as it appeared on **the** screen, pronouncing each item as quickly, but as accurately as possible. Reaction times and pronunciation errors were recorded for later analysis.

Results and discussion

An analysis of variance (ANOVA) of the reading times showed significant main effects of group ($F_{(2,39)} = 44.06$, $p < 0.01$) and word type ($F_{(1,39)} = 77.80$, $p < 0.01$), an interaction between word type and consistency ($F_{(1,39)} = 17.09$, $p < 0.01$), and a three-way interaction between group, word type, and consistency ($F_{(2,39)} = 4.99$, $p < 0.05$).

Dunnett T3 post-hoc analyses confirmed that the PD responded significantly faster across all conditions. The PD participants were significantly faster than both the TAA and HYA participants when reading all four classes of stimuli (consistent words, consistent nonwords, inconsistent words, inconsistent nonwords) ($p < 0.05$). The reaction times of the TAA and HYA participants were only significantly different when reading the inconsistent nonwords ($p < 0.05$). See Figure 1.

For the number of errors, ANOVA revealed significant main effects of group ($F_{(2,39)} = 52.55$, $p < 0.01$) , word type ($F_{(1,39)} = 109.74$, $p < 0.01$, and consistency ($F_{(1,39)} = 103.71$, $p <$

0.01), and significant interactions between group and word type ($F_{(2,39)} = 24.96$, $p < 0.01$, and group and consistency $F_{(2,39)} = 8.64$, $p < 0.01$). See Figure 2.

Dunnett T3 post-hoc analyses revealed that the PD group's pronunciation accuracy did not significantly differ from the TAA and HYA participants when reading consistent or inconsistent words ($p > 0.05$), but was significantly different from both groups when reading consistent and inconsistent nonwords ($p < 0.01$). The pronunciation accuracy of the TAA participants differed from the HYA participants when reading the inconsistent nonwords ($p < 0.05$). Hence there are clear signs of people finding reading more difficult as they age typically.

In summary, the PD group were faster than the other two groups, but importantly for our hypotheses they had difficulty in reading pronounceable nonwords as shown by the number of errors. We cannot explain the results in terms of a speed-error trade-off because of the interactions found in the error data where the PD group were selectively worse on the accuracy measure with nonwords but faster in all conditions. There are also signs of typically ageing adults showing reading difficulties.

The errors made by the PD speakers, and, to a lesser extent, TAA speakers resemble the errors made by people with acquired phonological dyslexia (Caccappolo-van Vliet, Miozzo, & Stern, 2004). Speakers tried to simplify the nonword and generate analogies using lexical knowledge. Specifically, they made lexicalisation errors, where they produced words for nonwords (e.g. probe for brobe); in the PD group lexicalisation errors accounted for 64% of the errors, with consonant substitutions accounting for 17%, and no responses or production of a completely wrong word or nonword 11% (with other rare errors including vowel substitutions).

Hence we claim that ageing makes us phonologically dyslexic to some degree; but to what degree?

Correlations with neuropsychological data in the PD group

Reading ability on nonwords correlated significantly and negatively with performance on the Phonological Abilities test and the WAIS Vocabulary score, suggesting that PA is essential for nonword reading (see Table 1). There were no significant correlations with word reading ability.

In our background neuropsychological assessments (Appendix 1), the PD group performed worse on measures of frontal-lobe functioning (ToH (moves & time); WCST perseverative errors and completion; Verbal Fluency & Written Fluency). All three groups performed close to ceiling at reading and understanding words (all $p < 0.05$). The PAT and PALPA data (Appendix 2) confirmed our earlier (Harley et al., 2011) finding that PD group performed significantly worse ($p <0.05$) than the TAAs, and the TAAs in turn performed worse than the HYAs ($p < 0.01$) on the PAT Phonological Abilities Test (Muter, Hulme, & Snowling, 1997). For PALPA, as expected the pattern of results was mixed: tasks that tapped PA, such as written and auditory rhyme judgement, showed a significant impairment in the performance of the PD group. However, there were no differences between groups when reading words, making lexical decision to words, or comprehending meaning on these particular tasks. However, our hypothesis is that ageing should cause us to become phonologically dyslexic. Consistent with this idea, we found that the PD group performed significantly worse at making lexical decisions about nonwords.

For the PD group, further correlation analyses revealed that consistent word reading times were positively correlated with consistent nonword reading times (rho = 0.66, N = 14, $p < 0.05$) and inconsistent word reading times (rho = 0.68, N = 14, $p < 0.01$). Consistent nonword reading times were significantly correlated with consistent word reading times (rho = 0.66, N = 14, $p < 0.05$), inconsistent word reading times (rho = 0.89, N = 14, $p < 0.005$), and inconsistent nonword times (rho = 0.83, N = 14, $p < 0.005$). Inconsistent real word reading times were positively correlated with inconsistent nonword reading times (rho = 0.77, N = 14, $p < 0.005$). These correlations show consistency of performance across conditions such that the PD participants who took the longest to respond did so across all experimental conditions.

We also found that written fluency repetitions were significantly negatively correlated with consistent real-word reading time (rho = -0.59, N = 14, $p < 0.05$) and inconsistent nonword reading times (rho = -0.63, N = 14, $p < 0.05$). Inconsistent word errors were also significantly positively correlated with the number of semantic fluency repetitions (rho = 0.59 N = 14, $p < 0.05$). Repetition errors on the written and semantic fluency tasks of course suggests a maintenance and monitoring failure such that in order to avoid such errors the individual must keep in mind what information has already been produced and identify repeated information. We used the written and semantic fluency task as a general measure of executive function and so we assume these correlations suggest that lower level performances were associated with a PD-related executive function impairment, namely impaired maintenance and monitoring.

We found similar associations for the typically ageing adults, with consistent nonword response times significantly correlated with inconsistent word (rho = 0.64, N = 14, $p < 0.05$), and inconsistent nonword (rho = -0.81, N = 14, $p < 0.001$) response times. Also, inconsistent nonword response times were significantly positively correlated with inconsistent nonword response times (rho = 0.82, N = 14, $p < 0.001$). Also, the number of consistent word errors was significantly positively correlated with inconsistent word (rho = -0.58, N = 14, $p < 0.05$) and inconsistent nonword (rho = 0.58, N = 14, $p < 0.05$) response times. The number of inconsistent nonword errors was significantly positively correlated with consistent word errors (rho = 0.61, N = 14, $p < 0.05$) and inconsistent nonword errors (rho = 0.54, N = 14, $p < 0.05$). As with the PD participants appears there was consistency across experimental conditions such that the TAA participants who took the longest to respond, and who made the most errors, did so across all experimental conditions.

We also found the **TAA** participants' letter fluency scores were significantly negatively correlated with consistent nonword errors (rho = -0.70, N = 14, $p < 0.01$) and inconsistent nonword pronunciation errors (rho = -0.57, N = 14, $p < 0.05$). As noted for the PD participants, our fluency tasks were employed as a measure of executive function and thus we infer that the increased fluency rates were related to increased executive control and thus improved nonword reading performance among the **TAA** participants. The role of executive function in the TAA participants real and nonword reading performances is further supported by the finding that the **TAA** participants' WCST performances were significantly positively correlated with inconsistent nonword reading times (rho = 0.55, N = 14, $p < 0.05$), and the number of consistent word response errors (rho = 0.61, N = 14, $p < 0.05$) and consistent nonword errors (rho = 0.56, N = 14, $p < 0.05$). **Hence we conclude that it is the degree of executive processing impairment and the associated degradation of linguistic awareness that leads to phonological dyslexia in ageing.**

Experiment 2

Nonword repetition

In Experiment 2 we tested our participants' repetition abilities. Failure of nonword repetition in stressed conditions is usually thought to be part of the GPD complex. Therefore if ageing causes loss of phonological skills, we should observe age-related deficits. We used the same N=14 participants as in Experiment 1. We employed a 3x2 mixed design of group and type of pronounceable nonword, with levels of high and low phonotactic probability (i.e. very and less word-like, e.g. cammerine v. sliniculb), adapted from the Children's Test of Nonword Repetition (Gathercole, Willis, Baddeley, & Emslie, 1994).

Method

We asked ten independent raters to check that the two types of nonword (high and low phonotactic probability - abbreviated to HPP and LPP) were truly distinguishable, using a five-point scale ($t[38] = 18.73$, $p < 0.01$). Furthermore, the HPP (highly word-like) nonwords had a mean positional segment frequency of 4760.5 and 340.15 for biphone frequency, and the LPP (low word-like) nonwords had a mean positional segment frequency of 2448.3 and 125.5 for biphone frequency. After manipulating the phonotactic probability of the nonwords there was a significant difference in positional segment frequency between the revised phonotactically controlled HPP (highly word-like) nonwords and the LPP (low word-like) nonwords ($t(38) =$

-6.282, $p < 0.01$), and also a significant difference in biphone frequency ($t(38) = -8.69$, $p < 0.01$). Again, as Experiment 1, we measured reaction time and the number of errors.

Results and discussion

For the number of errors, a 3 x 2 (Group: PD, TAA and HYA) x Nonword Type (HPP, High Phonotactic Probability, so Highly Wordlike, and LPP, Low Phonotactic Probability, so Low Word-like) mixed Analysis of Variance revealed a significant main effect of nonword type ($F(1,39) = 93.371$ $p < 0.01$) and a significant interaction between group and nonword type ($F(2,39) = 5.89$, $p < 0.01$). The main effect of group was also significant ($F(2,39) = 33.68$, $p < 0.01$). The results are summarised in Figure 3. Our results thus suggest that ageing impairs our ability to repeat nonwords aloud, the effect being more pronounced for trials where the non word is least word-like. The effect is exacerbated by PD, particularly for the least word-like nonwords. This pattern of results is exactly what we would expect if ageing disrupts executive processing in a way that leads to a general phonological deficit.

The most common types of repetition error in all groups were substitution of one consonant for another (47% in the PD group), an inability to repeat at all (32%), or some form of lexicalization, where a nonword was converted into a word (10%). Given these selective differences, the controls we put in place, and the types of errors found, these difficulties cannot be explained in terms of PD related motor impairments, so that there is no evidence that pronunciation difficulties resulted from dysarthria.

The number of pronunciation/repetition errors produced correlated significantly with performance on the Tower of Hanoi test, confirming that frontal executive processes are involved in this task, and with the number of perseverative responses in the Wisconsin Card Sorting Task (Appendix 1). This correlation shows that participants stuck in a response set perform also worse on the repetition task.

The reaction times for pronouncing/repeating nonwords are summarised in Table 2. A 3x2 mixed ANOVA found significant effects of nonword type on reaction time (with all groups being slower to repeat low word-like nonwords compared with high word-like nonwords on RT), $F(1, 39) = 156.4$, $p < 0.01$. There was no significant interaction between group and nonword type ($F(2,39) = 3.02$, $p > 0.05$), or significant main effect of group ($F(2,39) = 2.36$, $p > 0.05$).

Why are participants slower to repeat the more word-like words? We believe this difference arises because the more word-like a word, the more interference there is from real words - that is, the participant spends time checking that the word-like nonwords really are nonwords. The greater one's phonological skill, the more sensitive the participant is to this difference; hence the HYA group spend most time checking, and the PD group of course spend the least time checking. This finding is consistent with the finding that PD participants responded so quickly across all conditions in Experiment 1.

General discussion

Our results suggest that as we age we begin to lose some of our reading skills: effectively, ageing provokes mild phonological dyslexia.

We demonstrated that typical ageing increases the number of reading errors made on nonwords, and that people with Parkinson's disease make more errors than typically ageing individuals. We suggest our results are underscored cognitively by a specific impairment in processing and remembering phonological information underscored by general phonological deficit (e.g. Farah, Stowe, & Levinson, 1996; Harm & Seidenberg, 1999) and neurally by age-related deterioration of the frontostriate loop.

The fact that the PD group name words faster at first seems paradoxical. It cannot be explained as a simple speed-error trade-off because there was no significant correlation between reaction time and error rate *within* the PD group. Furthermore many of the errors that they do make are visually based rather than pronunciation based. We can explain the PD participant's somewhat counter-intuitive quick responding as a function of impaired executive processing, such that the absence of monitoring and deliberative processing enables quicker responding overall. We therefore hypothesise that the output of word naming and repetition a two-stage process, with an obligatory automatic stage of reading, involving retrieval and phonological compilation, followed by a second stage of checking. The executive processes we typically run are absent in PD and restricted in normal ageing, leading to an ability to respond faster but a difficulty in assembling pronunciations for nonwords. Exactly the same checking process applies in the repetition task. A lack of metalinguistic skill leads to faster responding in the impaired group.

Further evidence for this argument is provided by the general pattern of reading times across all three groups. In our reading experiment the HYA group named on average unusually slowly (around 1000 msecs rather than the more typical 500-700 msecs). Hence some aspect of our design, probably the way in which our materials were blocked, must have induced the HYA participants to read slowly and cautiously. This additional caution, most likely representing post-access checking, is ameliorated in the TAA group and almost completely absent in the PD group. Further research should explore manipulating the presentation of materials in a way that enables the possibility of checking to be tested systematically.

There has been an increased awareness recently of the role of executive processing and other general cognitive processes in what at first sight appear to be automatic language impairments, and their importance in treatment (see, for example Connor, & Fucetola, 2011; Harley et al., 2011). Our findings here add to the body of knowledge that is starting to show that although there might indeed be some hard-wired, language-specific processes, they should not be considered in isolation, particularly when it comes to considering the effects of damage to those processes, the way in which the rest of the language and cognitive system reorganises to accommodate that damage, and how general resources should be mobilised to treat such damage (see, for example, Allen, Martin, & Martin, 2012; Difrancesco, Pulvermuller, & Mohr, 2012; Hernandez-Sacristan, Rosell-Clari, Serra-Alegre, Quiles-Climent, 2012; Hoffman, Jefferies, Ehsan, Jones, & Lambon Ralph, 2012; Martin, Kohen, Kalinyak-Fliszar, Soveri, Laine, 2012; Martin & Reilly, 2012).

Our results have important implications for both the treatment of PD and how we should treat typically ageing adults. The result that checking is affected by ageing suggests that people receiving written instructions should be encouraged to slow down when reading, perhaps by reading to a long deadline. The result that ageing causes problems with nonwords has important implications for how older adults learn new words. Our results are important not just because they show that ageing may lead to difficulty in reading, but because problems with phonological awareness leads to a range of other difficulties, such as learning new words and names and new languages (Baddeley et al., 1998). Acquisition of new words speaks to the issue of accessibility and social inclusion for older people. Language develops over time, both with the impact of new technology and generally with fashion. For example, in June 2012 the Oxford English Dictionary added 2,500 words based on ‘super’ alone (Simpson, 2012). We should also consider the comprehension and production of new product names, particularly medications. Currently the main criteria for new drug names is the avoidance of similarity to previous ones or suggesting implications about drug efficacy. It has of course been observed that drug names tend to contain a disproportionate number of “x”s and “z”s, presumably to make the names stand out (Stepney, 2010), or even, we suggest, to make them sound more scientific. We have shown though that these are just the sorts of words that people with phonological awareness problems will find difficult, leading to potentially fatal confusion. We propose that creators of drug names should instead consider the linguistic problems of nonword reading as we age.

In conclusion, we have shown that typical ageing makes us slightly phonologically dyslexic, and that PD makes us strikingly so. We conclude that these deficits arise because of deteriorating phonological awareness, and that this may result from a general phonological deficit originating from the ageing of frontostriate loop, and perhaps other cortical regions, and an associated decline in executive processing and the ability to manipulate sounds and spelling-sound correspondence.

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Table 1. Significant relationships (Spearman's rho) between the PD group's neuropsychological assessment scores and their performance in the word and nonword reading task (n=14).

Neuropsychological Assessments	Mean Word Errors	Mean Nonword Errors	Mean Consistent Errors	Mean Inconsistent Errors
PAT	-	-0.64 *	-	-
WAIS Vocabulary	-	-0.63 *	-	- 0.54 *
PALPA 25 - Nonwords	-	-0.59 *	-	-

*significant at the 0.05 level; ** significant at the 0.01 level

Note: PAT = Phonological Abilities Test; WAIS Vocabulary = Wechsler Adult Intelligence Scale; PALPA 25 – Nonwords = lexical decisions about nonwords.

Table 2. Mean RT and SD for nonword types for each group (msecs).

GROUP	**HPP**		**LPP**	
	Mean RT	SD	Mean RT	SD
PD	507	-172	208	-198
TAA	596	-269	272	-123
HYA	671	-105	288	-167

Note: HPP = high phonotactic probability - highly word like; LPP = low phonotactic probability - low word likeness.

Appendix 1

Demographic characteristics and mean neuropsychological assessment scores for all participant groups

	PD (n=21)		**TAA (n=20)**		**HYA (n=14)**	
	Mean	SD	Mean	SD	Mean	SD
Age	68.81	-8.26	74.55	-7.07	27.93	-2.90
Yrs Educ. Yrs with PD	12.0 9.90	-2.7 4.81	12.65 -	2.54	15.0 -	1.71
Clock	6.62	1.66	7.15	0.88	7.71	0.47
WAIS Digit	6.74	2.52	9.03	1.87	11.86	1.20
FOG overall	23.86	17.79	-		-	
GDS GDS PD	8.48 4.0	5.18 3.42	4.95 -	-4.59	2.64 -	1.55
Hope Overall	25.14	3.20	26.10	2.73	24.36	3.43
Hope Agency	12.29	2.05	13.30	1.38	12.07	1.98
Hope Pathway	13.05	1.69	12.80	1.74	12.29	1.64
MMSE	28.64	1.22	26.29	2.40	24.36	3.40
NART	119.43	7.67	124.21	7.05	124.14	3.26
PAT	43.48	7.69	50.15	12.48	66.07	7.77
ToH Moves	14.62	7.35	10.30	4.34	7.50	1.02

ToH Time (secs)	93.79	67.48	60.05	36.99	25.62	27.05
Total Verbal Fluency	79.81	34.05	102.35	28.21	113.64	13.27
Total Written Fluency	22.57	9.58	30.95	11.03	36.36	5.94
WAIS Vocab	51.43	10.01	55.0	8.42	52.29	10.04
WCST Overall	34.56	15.44	23.41	20.28	11.22	1.05
WCST Persev.	13.73	8.06	16.44	10.28	7.36	2.02

Note: Clock = Clock Drawing; WAIS Digit (mean forwards & backwards) & Vocab = subtests Wechsler Adult Intelligence Scale; FOG = Freezing of Gait; GDS General = Geriatric Depression Scale; GDS PD = GDS Score when questions insensitive to PD removed; Hope Overall = Hope Scale (Agency & Pathway scores combined); MMSE = Mini Mental State Examination; NART = National Adult Reading test; PAT = Phonological Abilities Test; ToH Moves = Tower of Hanoi (number of moves to completion); TOH time = Tower of Hanoi (time (secs) to completion); Total Verbal Fluency (number of words produced for Semantic & Letter Fluency combined); Total Written Fluency = number of written words produced; WCST overall = Wisconsin Card Sorting Test (success rate, lower score reflects better performance; WCST persev = Wisconsin Card Sorting Test (number of perseverative responses, higher scores reflect being stuck in set).

Appendix 2

Mean scores and standard deviations on assessments from the Psycholinguistic Assessment of Language Processing in Aphasia (PALPA, Farah, Stowe, & Levinson, 1996) for all participant groups

	PD (n=21)		**TAA (n=20)**		**HYA (n=14)**	
	Mean	SD	Mean	SD	Mean	SD
PALPA 13a Digit Span (Repetition)	4.48	1.12	6.10	0.79	6.64	0.50
PALPA 13b Digit Span (Matching)	5.14	1.32	6.20	0.95	6.71	0.47
PALPA 14 Rhyme (Picture) Rhyme judgement Non-rhyme judgement	17.38 17.43	-1.36 1.60	19.30 18.25	-1.87 4.73	19.86 -0.36	20 (0)
PALPA 15a Rhyme Auditory	52.86	-3.15	55.65	2.48	56.71	-0.73
PALPA 15b Rhyme Written	52.00	-3.05	54.20	-2.63	57.14	0.67
PALPA 25 Lexical Decision Words Nonwords	59.76 59.10	-0.89 1.58	59.75 58.60	-0.55 2.16	60 60	0 0
PALPA 31 Reading	79.81	-0.51	79.50	-0.76	80	0
Imageability & Reading	89.48	0.87	89.75	0.55	90	0

PALPA 40 Spelling to Dictation	38.33	2.54	38.65	2.56	40	0
PALPA 47 Picture Matching Spoken Word	39.95	0.22	39.95	0.22	40	0
PALPA 48 Picture Matching Written Word	40	0	39.90	0.31	40	0
PALPA 50 Written Synonym Judgements						
▪ High Imageability	29.43	-1.08	29.95	-0.22	30	0
▪ Low Imageability	29.48	0.75	29.25	(1.21)	30	0

Appendix 3

Materials

Consistent words

bath beef bleed breed buff bust cold code deal dean dream dune feet goad greet haze heat heed hoop lobe lode meld mode must note pink plain port posh probe puff shore soil sole soon spool steal sweet told wail weak wilt wore

Inconsistent words

both been blood bread bull bush comb come dead deaf dread done foot good great have head hood hoof lose love mild move most none pint plaid post push prove pull shove said some soot spook steak sweat tomb wool wear wild were

Consistent nonwords

cath heef dreed sheed wuff nust pold gode feal hean bleam mune peet soad steet taze weat beed moop cobe hode beld pode sust wote bink prain bort wosh brobe suff plore hoil lole doon grool sweal speet dold lail meak pilt dore

Inconsistent nonwords

coth heen drood shead wull nush pomb gome fead heaf blead mone poot sood steat tave wead bood moof cose hove bild pove sost wone bint praid bost wush brove sull plove haid lome doot grook sweak speat domb lool mear pild dere

Figure legends

Figure 1. Mean naming times to begin correct pronunciation of target stimuli for PD, TAA, and HYA participants.

Figure 2. Number of errors for PD, TAA, and HYA participants.

Figure 3. Effect of group and word-likeness on number of errors in the repetition task.